

THE TEACHING OF CHEMISTRY IN TROPICAL SECONDARY SCHOOLS

by

N. F. NEWBURY

Being VOLUME IX of the
UNESCO HANDBOOKS
ON THE TEACHING OF SCIENCE
IN TROPICAL COUNTRIES
General Editor: F. Smithies

London
Oxford University Press

General Introduction

Scientific discoveries, and their applications in industry, communications, agriculture, medicine and war, have caused great changes in the lives and habits of most of mankind during the last 150 years. Men's ways of life and thought are not yet accustomed to this change.

Because of the destructive power of some scientific inventions, many men have lost faith in the future of mankind; because of the marvellous power of other scientific inventions to increase the well-being of mankind, many men have expected Science to find an answer to all life's problems. Both of these views of Science show a misunderstanding of what Science is and what scientists can or cannot do. How can such misunderstandings be prevented?

It is not enough to train expert scientists; they are necessary, but it is equally necessary that ordinary folk should know what scientists try to do and how they try to do it. Before they can understand the scientists' work, non-scientists must first learn what Science is. For this, a knowledge of scientific facts and principles is not as important as an understanding of Science and the methods used in its study. And this understanding of Science must become a part of men's everyday thought.

Understanding comes through education; but the understanding of Science must not remain merely an aim of education: it must become part of it. In schools, isolated courses in one or another aspect of science must be replaced by a view of Science as a whole, and of its part in learning.

That is the basis of the project, in this series of books, to advise and help teachers of Science. The emphasis is put on methods of teaching and lines of approach to the subject matter, rather than on the content of a syllabus. It is hoped that, by the use of good methods, the teacher will be able to lead his pupils towards an appreciation of scientific methods and an understanding of Science. Through sound education, not only will the few receive the basic training that will fit them for specialization later, but the many will grow up with an intelligent grasp of Science and its significance in their social and economic life.

THE SCOPE OF THE SERIES

There are ten volumes in the series, designed specially for Science teachers in tropical areas and countries that are not yet highly organized and industrialized, and where the applications of science are not yet apparent in the daily life of all citizens:—

- I The Teaching of Science in Tropical Primary Schools
- II The Teaching of Rural Science in Tropical Primary Schools
- III The Teaching of Health Science in Tropical Primary Schools
- IV The Teaching of Home Science in Tropical Primary Schools
- V The Teaching of Arithmetic in Tropical Primary Schools
- VI The Training of Primary School Science Teachers
- VII The Teaching of General Science in Tropical Secondary Schools
- VIII The Teaching of Physics in Tropical Secondary Schools
- IX The Teaching of Chemistry in Tropical Secondary Schools
- X The Teaching of Biology in Tropical Secondary Schools

Volume I is concerned with the teaching of Science to children in the age-group 6-12 approximately, who are receiving their first formal education. It is designed for students in teacher-training colleges and practising teachers in primary schools. They are shown how to make the most of the children's natural interests.

Volumes II, III and IV also are written mainly for the benefit of the primary school teacher. They treat Science at the same level as Volume I, but from different aspects. Thus, Volume II is of especial value to teachers in rural schools: it does not give instruction about the teaching of 'Farming' or 'Agriculture', but uses these activities to give practical examples of scientific methods and principles in action. Similarly, in Volume III the importance of Health is the theme of Science teaching. The book will help any teacher, and will be of particular use to those in places where great efforts are being or should be made to raise standards of health. Volume IV associates the teaching of Science with life in the home, as the basis of a Science course for girls.

Volume V deals with the fundamentals of Arithmetic as an essential component of Science.

Volume VI is concerned with the training of teachers who are to give the science lessons in Primary Schools, and who, it is hoped, will adopt the methods suggested to them in Vols. I-V.

Volume VII carries the teaching of General Science to the earlier years of a secondary course: 4-5 years in the age-group 11-18 approximately. It shows how the work can be regarded both as a course of educational value for its own sake and also as a foundation for further studies. It gives full information on laboratory design and organization, minimum equipment, and maintenance.

Volumes VIII, IX and X discuss the teaching of the three branches of Science usually taught in the higher classes of secondary schools. The place and treatment of these subjects in junior work also is considered briefly. The chief aim of these three volumes is to assist the teacher of students who are beginning to specialize, probably with a university career in view, i.e. those who are undertaking 'sixth-form' or 'scholarship' or 'first-year undergraduate' studies.

THE AIMS OF THE SERIES

Thus, the intention of this series of books may be summarized as follows:—

(a) To help teachers of Science to realize the importance of their work in the community; to help them to guide their pupils to an understanding of the significance of everyday occurrences and experience; and so to educate them to take an intelligent interest in social and economic affairs and to be useful members of their community.

(b) To show how Science instruction can be organized as a continuous whole, in accordance with modern views of co-ordinated teaching, and how it can be adapted to meet any special requirements of a particular type of school.

(c) To suggest a comprehensive scheme of teaching based on sound educational and psychological principles.

(d) On the basis of the practical teaching experience of the authors and the general editor and their advisers, to outline the content of Science teaching from the Primary to the Pre-University level.

This series originates in the need, so often expressed to the United Nations Educational Scientific and Cultural Organization, especially by those responsible for education in tropical countries, for more and better science teaching in primary and secondary schools. These

GENERAL INTRODUCTION

educationists share world-wide opinion that training in Science is essential to modern education, to the improvement of health and living conditions and the promotion of agriculture and industry. In response to their appeal Unesco conceived the plan and the method of presentation of the series and subsidized the preparation of the ten manuscripts. Responsibility for choosing the authors and the general editor and for the cost of publication was undertaken by the Oxford University Press in agreement with Unesco.

Preface to Volume IX

This book is concerned with the teaching of Chemistry at the secondary level, dealing with the instruction of pupils in the approximate age-group 11-18. It is intended chiefly for the use of young Science teachers in secondary schools and for teachers-in-training, but it will also present new points of view to more experienced Science teachers and should prove to be of interest to other educationists. Further, the book will be of value in school and public libraries, as pupils will be able to find out the reasons for the inclusion of Chemistry in the curriculum, and to make use of the charts and other reference material.

The book is parallel and complementary to Volumes VIII and X, and treats Chemistry as a separate science at the Pre-University stage for intending Science specialists. At the same time there is much advice and information for those who teach the subject to lower classes, either separately or as a part of a General Science course.

The teacher will find help in the selection of suitable material for Science lessons, and in the planning and carrying out of practical work. The chief aim is to show how scientific methods can be encouraged and how pupils can be led to an understanding of Chemistry and the work and procedure of the chemist. Much practical advice is given, but, although most aspects of Chemistry teaching are discussed, no attempt has been made to provide an exhaustive study of educational, philosophical and psychological influences. The treatment given, however, is sufficient to indicate the important part taken by Chemistry in the educational system of today.

The methods advocated in this book are necessarily the reflection of but one teacher's beliefs and experience, yet the author's object has been to collect, and to arrange in suitably available form, much scattered information. As far as is known, only the author has previously written a book devoted exclusively to the teaching of Chemistry, but ideas and practical advice have been assimilated from other Science teachers and many sources.

The author would like to express his sincere thanks to many

PREFACE TO VOLUME IX

friends for the help freely given during the writing of this book. He is greatly indebted to Mr. F. Daniel for his helpful suggestions in the planning of the contents. He is grateful to Messrs. Heinemann and Co., the publishers of his *Teaching of Chemistry*, for their willing permission to base the present book on that work.

N. F. NEWBURY

St. Helens, May 1953

Contents

I THE DEVELOPMENT AND PRESENT POSITION OF CHEMISTRY	1
The early history of Chemistry · The 'makers of Chemistry' · The present position of Chemistry · The contribution of Chemistry to civilization · Some material benefits derived from the advance of Chemistry · Some non-material benefits · The social implications— <i>The social responsibilities</i>	
II REASONS FOR THE INCLUSION OF CHEMISTRY IN THE SCHOOL CURRICULUM	11
The benefits derived from the study of Chemistry— <i>Transfer of training</i> · The special application to teaching in schools · Criticisms of Chemistry teaching; answers to the criticisms	
III SYLLABUSES IN CHEMISTRY	21
(A) FOR JUNIOR STUDENTS	
The framing of an elementary Chemistry syllabus— <i>Difficulties encountered by young teachers</i> —The main aims in building up a syllabus—Other considerations · Notes on the Chemistry section of a General Science course · Basis of the Chemistry section of a General Science course—First and Second Years—Third and Fourth Years—Features of the syllabus · Other basic principles	
(B) FOR ADVANCED STUDENTS	32
Teaching Chemistry to more advanced students— <i>The preparation of lessons</i> —Methods of studying—The basis of courses in Inorganic, General and Physical Chemistry—The basis of a course in Inorganic Chemistry—Organic Chemistry—Notes on a detailed syllabus · Syllabus of General, Inorganic and Physical Chemistry · Syllabus of Organic Chemistry · Subject-matter for lessons ·	

Organization of practical work in the advanced course · Science courses for non-specialists

IV THE TEACHING OF ELEMENTARY CHEMISTRY

56

Preparations on obtaining a first appointment · The first two lessons in Elementary Chemistry · General methods in later lessons · The end of the first term · Problems to be considered as the teacher becomes more experienced · The development of the individual pupil—*The interests of pupils* · The progress of a lesson · Tests in Chemistry—*Revising from an experiment—Varied types of tests—Recent developments in testing Chemistry—Classification of tests in Chemistry*

V ORGANIZATION OF THE SCHOOL LABORATORY

85

Stocking the laboratory—*Chemicals—Apparatus—The stock-book and other records* · The storage of chemicals—*Special precautions in storing chemicals—Further notes on chemicals—Deliquescent and hygroscopic substances—Efflorescent substances—Dangerous and expensive substances—Reagents—2N solutions of the commoner reagents* · Storage and care of equipment—*Schools without a laboratory assistant or steward—Schools with a laboratory assistant or steward—The pupils' benches and drawers* · Improvisation and substitutes—*Some home-made apparatus—Improvised apparatus* · The amounts of substances to be used in experiments—*Calculation of quantities to be used—The approximate amounts of chemicals theoretically required to yield 3 litres of a gas at S.T.P.—Amounts of substances required for other experiments—General rules for preparing substances—Dangerous gases—The cost of experiments* · Laboratory rules for pupils · First-aid in the laboratory · Dangerous chemicals and experiments—*Inflammable or explosive substances—Poisonous substances—Causing burns on skin—Dangerous reactions*

**VI THE RELATIVE MERITS OF INDIVIDUAL
AND DEMONSTRATION METHODS** 120

Individual experiments · The heuristic method in its elementary stages—*History*—*Benefits of the heuristic method*—*Criticisms of the heuristic method*—*Summary of conclusions* · Demonstration methods · Differing approaches for boys and girls · Relative merits of the demonstration and individual methods · Conclusions on the teaching of practical Chemistry · Review of research work done in the U.S.A. · Final summary

**VII THE TREATMENT OF QUANTITATIVE
WORK**

138

Historical introduction—*Errors in classical experiments* · *Introducing quantitative Chemistry* · Quantitative experiments—*Simple experiments for juniors*—*More advanced quantitative work*—*The magnitude of errors* · *Errors in quantitative work*—*Constant errors*—*Variable errors*—*The treatment of errors*—*Calculating the value of errors* · Summary · Chemical arithmetic

**VIII SMALL-SCALE APPARATUS AND
EXPERIMENTS**

157

Advantages of the small-scale approach · Apparatus and methods · Experiments with gases · Collecting gases · Revision chart for the preparation and properties of the commoner gases · Small-scale methods for juniors—*Outline of problems and experiments* · Small-scale methods for more advanced students—*Further modifications in experiments using small-scale apparatus* · Outline of further experiments

IX THE TEACHING OF CHEMICAL THEORY 176

Descriptive Chemistry · Atoms and molecules · Symbols, formulae and valency · Errors made by pupils in constructing equations—*Examples from*

CONTENTS

pupils' note-books • Building up elementary equations • More advanced equations • Chemical equilibrium • The atomic theory • Scientific doubt and attitudes • Modern research in Chemistry

X THE VARIED INFLUENCES OF LANGUAGE ON THE LEARNING OF CHEMISTRY

198

Using scientific language • Scientific words • Scientific facts known to beginners • Scientific words in periodicals and newspapers • Learning chemical names—*Definitions and terms* • Training in note-making—*Extracts from pupils' note-books* • The marking of Chemistry note-books—*Errors in the pupils' note-books*

XI THE USE OF DIAGRAMS, CHARTS AND OTHER VISUAL AIDS

218

Diagrams and drawings in the laboratory notebook—*Comparison of the methods used in textbooks*—*The value of drawings*—*Sectional drawings*—*Errors frequently made by pupils*—*The use of drawings and diagrams* • Diagrams and charts for laboratory notice-boards • Models • Other forms of teaching aids—*Films and film-strips*

XII TRAINING IN EXPERIMENTAL TECHNIQUE

236

Use of simple apparatus • The comparative use of apparatus • Correlation of practical work • Incidental teaching • Practical problems • Generalizations • A class-problem in the first year • Devising apparatus to solve practical problems • Laboratory instruction—*Some problems* • Chemistry as a hobby

XIII BASING THE SCIENCE COURSE ON ENVIRONMENT: SCHOOL PROJECTS

251

Chemistry and the General Science syllabus—*Applications to elementary Chemistry* • A Science course for a coastal town • Projects connected with elementary Chemistry • The rural environment in tropical areas

XIV SCHOOL EXHIBITIONS AND CHEMICAL CLUBS	257
Necessary preliminaries · A project on coal · A project on water · Other projects · Individual demonstrations · Advantages of an exhibition · Exhibits · Chemical clubs	
XV THE DESIGN OF A CHEMISTRY LABORATORY	263
General principles · Some details · The junior laboratory · The advanced laboratory · The mains services · The preparation-room · The store · The balance-room · The lecture-room	
APPENDIXES	
A. IMPORTANT NAMES AND DATES IN THE DEVELOPMENT OF KNOWLEDGE OF ATOMIC ENERGY	273
B. BOOKS FOR THE CHEMISTRY LIBRARY	275
C. LIST OF CHEMICALS	279
D. LIST OF APPARATUS FOR THE CHEMICAL LABORATORY	283
E. LIST OF SUITABLE CONTENTS FOR A FIRST-AID CUPBOARD	289
F. CHEMICAL NAMES AND FORMULAE OF SOME COMMON SUBSTANCES	290

INDEX

List of Illustrations

FIGURE	PAGE
1 The history of Chemistry—a chart	2
2 Aliphatic compounds: a chart with ethyl alcohol as the starting-point	41
3 Aliphatic compounds: a more detailed chart starting with starch and the sugars	42
4 Aromatic compounds: a chart starting with coal-tar and benzene	44
5 Aliphatic nitrogen compounds: a chart indicating the synthesis of homologues, etc.	45
6 Apparatus to show the principle of the Bunsen burner	61
7 Demonstration experiments:	64
(a) Burning bubbles of coal-gas	
(b) Burning hydrogen from the action of sodium on water	
8 The preparation of ammonia gas (small-scale)	65
9 The 'ABC' of the Gas Laws: a chart	67
10 The 'Nitrogen Cycle': a detailed chart	71
11 The 'Carbon Cycle': a chart	80
12 The measurement of the volume of a gas (with a substitute for Hempel's burette)	93
13 Home-made equipment:	93
(a) A pipette, or burette, stand (vertical)	
(b) and (c) Horizontal stands for glass tubes	
14 More home-made equipment:	100
(a) A test-tube rack (made from a box)	
(b) A test-tube holder (made from wire)	
15 A piece of home-made apparatus, for use as:	100
(a) A test-tube stand	
(b) A filter stand	
(c) A beehive shelf	
16 Improvised Liebig condensers: two designs	101
17 Other improvisations:	102
(a) For a filter-funnel support	
(b) For a crucible holder, etc.	

FIGURE	PAGE
18 Unconventional apparatus for experiments:	102
(a) To show that water contains dissolved air	
(b) To show the effect of carbon dioxide on burning candles	
(c) To find the percentage volume of oxygen in the air	
19 More unusual apparatus:	102
(a) To show hydrogen burning in a limited air supply	
(b) To show that plants evolve oxygen in sunlight	
20 The electrolysis of brine (small-scale)	103
21 Chart showing the quantities of materials required for the preparation of 3,000 c.c. of the common gases	105
22 Apparatus for finding the percentage by weight of carbon dioxide in chalk	107
23 The reduction of oxides by hydrogen or coal-gas:	144
(a), (b), (c) and (d) Various types of apparatus for quantitative experiments	
(e) A simple apparatus for the qualitative experiment	
24 A test-tube and funnel stand	160
25 Small-scale distillation	160
26 Apparatus for distillation in steam (small-scale)	160
27 The preparation and collection of a small volume of a gas	161
28 The preparation of gases: unit small-scale apparatus	162
29 A combined test-tube rack and stand	163
30 The preparation of, and tests for, gases: a chart	164
31 Condensation of water evolved from a heated hydrate	166
32 An experiment with ozone (small-scale apparatus)	167
33 The action of steam on magnesium: a small-scale experiment	167
34 The electrolysis of concentrated hydrochloric acid solution (small-scale)	168
35 A method of rapid qualitative testing for radicals	170
36 The valencies of some common radieals: a chart	179
37 A chart of the chemical names and formulae of some common substances	181
38 Examples of mistakes in a sectional diagram	224
39 Sulphur and its compounds: a chart	228

FIGURE	PAGE
40 The manufacture of sodium: a model of the Castner process	230
41 The Castner process: interior of the model	231
42 The laboratory supply of hydrogen sulphide, carbon dioxide, hydrogen, etc.: substitutes for a Kipp's apparatus	243
43 The small-scale preparation of oxygen: to show that manganese dioxide is a catalyst	244
44 The law of conservation of mass: pupils' suggestions for experimental proof (using two liquids)	249
45 The law of conservation of mass: further experimental suggestions	250
46 The junior chemistry laboratory (for about 30 pupils): a suggested lay-out	264

CHAPTER I

The Development and Present Position of Chemistry

The early history of Chemistry

Although of comparatively young growth, Chemistry has gained a secure position in the curricula of schools, technical colleges and universities, both as an essential part of general education for life and as a separate branch of Science. The importance of the subject is now recognized by all educationalists. A study of the development of Chemistry itself and of its introduction into educational institutions reveals a steady advance to its present status.

The word Chemistry is probably derived from the Egyptian word *chemela*, meaning Egypt, the black land of the Nile. The Chinese and the Egyptians carried out simple operations of filtering, evaporation, distillation and sublimation. Substances were purified and reactions studied in the everyday processes of brewing, tanning and extraction of metals, and in making pottery and glass.

The Greeks, notably Aristotle (384-322 B.C.) and Democritus, based their views of the structure of matter on pure reasoning, without confirmation by experiment. At the beginning of the seventh century the Arabs systematized the then known facts. They also prepared dyes, glass, silver nitrate, hydrochloric acid, nitric acid, sulphuric acid and ammonium chloride. Further, they devised new types of apparatus and built libraries and laboratories. By conquering Spain they first carried the knowledge of Chemistry into Europe. Much of their time was, however, given to Alchemy. The alchemists were preoccupied in trying to discover the universal solvent (a liquid to dissolve all other substances), the elixir vitae (a cure for all illnesses and diseases) and the philosopher's stone (a substance which changes commoner metals into gold). Unsuccessful attempts to attain these aims led to much fraudulent practice and little development of Chemistry as a science. Indeed, except in the design of apparatus

Date	Period	Notes
B.C.		
2000	Egyptian	Origin of Chemistry in Egypt & Mesopotamia
1800		
1600		
1400	Ancient Chemistry	
1200		
1000		
800		
600	Early Chemistry	
400	Greek	Greek philosophers:— Aristotle (384-322), Thales, Democritus, Plato
200		
0		
A.D.		
200		
400		
600	Arab Alchemy	Arabs conquered Egypt
800		Geber (702-766)
1000		
1200		
1400		
1600	Iatro-chemistry Phlogiston Theory	Alchemy appeared in Europe (1100) Renaissance (1400) Printing invented
1800	Modern Chemistry	Roger Bacon (1250) Paracelsus (1493-1541) Francis Bacon (1561-1626) Robert Boyle (1627-1691) <i>'Makers of Chemistry'</i>
2000		Black 1728-1799 Cavendish 1731-1810 Priestley 1733-1804 Scheele 1742-1786 Lavoisier 1743-1794 Volta 1745-1827 Dalton 1766-1844 Avogadro 1776-1856 Davy 1778-1829 Gay Lussac 1778-1850

FIGURE 1.—The History of Chemistry—a chart
(A chart of this kind can be expanded as desired)

notably the development in the use of the balance by Black, little progress was made until the seventeenth century.

The name of Paracelsus (1493-1541) is connected with the period when chemicals were first used as medicines. Although an alchemist, Paracelsus emphasized the value of observation and the need to question the statements of older authorities. He thus helped to free this primitive science from superstition. This period of iatro-chemistry, or medical chemistry, was notable for improved methods of preparing and purifying chemicals for pharmaceutical uses.

Chemistry as a science dates only from the time of Robert Boyle. The foundation of scientific method was laid by Francis Bacon (1561-1626), who stressed the importance of accurate experiment and an orderly arrangement of facts. He brought to the forefront the inductive method of reasoning as a guide to investigation, that is, the process of discovering and proving general statements from particular cases.

A scientific method was now developing, and Chemistry was put on a firmer basis. Robert Boyle (1627-1691) is considered to be the founder of modern Chemistry. His papers on the structure of matter, combustion and the physical properties of gases are of prime importance. He did much to free Chemistry from the early superstitious ideas which clung to it and contended that Chemistry should be studied so that human knowledge could be increased.

A little later the important researches of chemists of different nationalities, chiefly Black (1728-1799), Cavendish (1731-1810), Priestley (1733-1804), Scheele (1742-1786), and Lavoisier (1743-1794), showed that Chemistry was becoming a science with vast possibilities. The work of these pioneers was concentrated on the properties and composition of air and water, the processes of respiration and combustion, the nature of acids and bases, and the preparation of the commoner gases. The present elementary Chemistry courses in schools are based on these topics. It is well nowadays to make some reference to their historical aspects in order to show pupils how Chemistry has developed.

Notes on 'the Makers of Chemistry' (see Figure 1)

van Helmont (1577/1580-1644) was a practical chemist who first used the term gas. He prepared different gases by the action of acids

on metals, by fermentation and by burning charcoal, and studied their properties.

Stahl (1660-1734) was the originator of the phlogiston theory of combustion which was no longer satisfactory when oxygen had been discovered. Phlogiston was assumed to be present in substances which burnt and to be given off during burning. Carbon and hydrogen were thought to contain much phlogiston. According to this theory, when lead oxide was heated with carbon the phlogiston from the carbon returned to form metallic lead; when lead itself was heated in air phlogiston was given off to form lead oxide.

Black (see Figure 1 for dates, etc.) was the great pioneer in quantitative Chemistry since he approached research through the use of the balance. He studied the relationship between calcium carbonate, calcium oxide, calcium hydroxide and carbon dioxide. He was the first chemist to recognize and study the properties of carbon dioxide.

Cavendish investigated the properties of carbon dioxide and hydrogen, studied the composition of air and water, and improved methods of collecting gases.

Priestley prepared many gases, including oxygen, nitrous oxide, nitric oxide, sulphur dioxide, hydrogen sulphide, ammonia, hydrogen chloride and silicon tetrafluoride. He improved the apparatus used to collect gases by displacement of liquids. He exploded a mixture of hydrogen and oxygen to form water and showed that oxygen played an essential part in the breathing of animals.

Scheele was essentially a chemist who worked in the laboratory, and he discovered chlorine, hydrofluoric acid, ammonia and (independently of Priestley) oxygen and hydrogen chloride. He studied the properties of hydrogen sulphide, arsine, manganese and barium hydroxide.

Lavoisier, a Frenchman and one of the most brilliant of all chemists, heated mercury in a known volume of air to form mercuric oxide. In turn, he heated the mercuric oxide to recover the mercury and oxygen and showed that the weight of the mercuric oxide was equal to the combined weight of the mercury and oxygen. Further, the weight of the oxygen lost from the air was equal to the weight combining with the mercury. He thus verified the law of conservation of mass. His studies disproved Stahl's phlogiston theory and he formulated the present theory of combustion: that breathing is

slow oxidation, that burning is rapid oxidation and that oxygen is necessary for breathing and burning.

Lavoisier also showed that water is a compound of hydrogen and oxygen and that air is a mixture. He collected and classified many of the then-known facts of Chemistry and proposed the present system of naming chemicals, including sulphates, carbonates and nitrates.

Dalton (1766-1844) formulated the basis of the atomic theory and thus gave a theoretical explanation to the laws of constant composition, of multiple proportions and of the volumes of gases reacting. He proposed the use of geometrical symbols to represent atoms.

The present position of Chemistry

The present position of Chemistry in schools, technical colleges and universities in progressive countries such as those in North America and North Europe is soundly established. The content of modern syllabuses and the methods of teaching are, however, largely determined by the requirements of such examinations as those for the General Certificate of Education, the National Certificate, and University Degrees. Increasing numbers of advanced students are preparing for these examinations, although in many cases the expansion of General Science has decreased the amount of time available for individual practical work in elementary Chemistry. It is not possible at this early stage to assess the full influence of teaching Chemistry as a part of General Science rather than as a separate subject. Further, incessant warfare or fear of war during the last fifty years has stressed the importance of Chemistry to both individual and community, and has led to new views on the philosophy of life and a consequent difference in approach to Science in general and to Chemistry in particular. There have been fundamental changes in the political background and economic outlook. The rapid increase in world population presents a fundamental problem in food supply. Many teachers take every suitable opportunity, especially with older boys and girls, to link their teaching with social problems and responsibilities.

The contribution of Chemistry to civilization

Chemistry is one of the major branches of Science. In simple terms it deals with the ways in which man obtains the materials he requires. It deals with the substances making up the universe, e.g. sea, air and land, and the way these materials behave when in contact with each other under certain conditions.

For convenience, two types of chemists are sometimes differentiated—the pure chemist and the applied chemist. The pure chemist seeks to explain and discover. His only motive is the desire to extend knowledge. He gains intellectual and aesthetic satisfaction in solving problems. Well-known examples of pure Chemistry are the discoveries of radium by Madame Curie and penicillin by Fleming. The applied chemist uses known facts to invent a device or to improve a manufacturing process for the immediate benefit of the community. His aim is primarily profit in discovering amenities which benefit mankind. The pure chemist is not concerned with obtaining results and conclusions of practical value, but, in principle, he investigates problems in which he is interested so that he may obtain new knowledge for its own sake. By contrast, the applied chemist has a definite purpose, and he is chiefly concerned with the methods and techniques of achieving this. Both classes are, however, interdependent and it is unwise to stress their separate functions unduly, since their aims, methods and efficiency are much the same.

The material and non-material benefits derived from the use and study of Chemistry cannot always be separated from those of other sciences, particularly Physics and Biology.

Some material benefits derived from the advance of Chemistry

1. *The contribution to improved health:* (a) By increasing available supplies of coal-gas, water, electricity, petrol and oil. (b) By increasing the length of human life by better medical attention; (the expectation of life,¹ at age 0, has been increased by nearly twenty years since 1900 in Great Britain where, on the average, a young man may now expect to live to about seventy and a young woman to about seventy-five). (c) By the discovery of anaesthetics, antiseptics and

¹ "Expectation of life" means the number of years a person may expect to live after the age he has already reached. It is, for each age, an average calculated

drugs, which have reduced pain and made it possible for operations to be increasingly successful; (in 1900, 136 English infants in every 1,000 died in the first month of their lives, but in 1950 this number was reduced to 28 per thousand). (d) By making sanitation more efficient: modern sewage systems, pure water supplies and better lighting and heating facilities are gradually becoming more widely available. (e) By reducing accidents and ill-health in industry through improved safety measures and devices, e.g. Davy's safety lamp, and improved conditions of ventilation. (f) By the gradual spread and application of a knowledge of dietetics, involving balanced diets, with special reference to vitamin requirements.

2. *The supply of foodstuffs.*—A greater variety of foodstuffs is now available over longer periods of the year through refrigeration, drying, canning and other methods of preservation. Increased yields of crops are made possible by the use of fertilizers; purer foodstuffs are now prepared; and harmful insects and animal pests can now be destroyed more effectively.

3. *The increase in comfort, convenience and pleasure.*—During recent years the general standard of living has been raised in many parts of the world. A greater variety of colours and new textiles is available; travelling is possible by train, ship, motor-car and aeroplane; television and wireless sets and cinemas are now regarded by many

from hundreds of thousands of cases. Available figures (given to the nearest year) are:

At age:	Great Britain				At age:	United States of America				
	Expectation of life		Average length of life to be expected			Expectation of life		Average length of life to be expected		
	Male	Female	Male	Female		Male	Female	Male	Female	
0	61	66	61	66	0	66	71	66	71	
1	64	68	65	69	1	67	72	68	73	
5	62	65	67	70	5	63	68	68	73	
10	57	61	67	71	10	55	63	65	73	
15	52	56	67	71	15	54	59	69	74	
20	48	52	68	72	20	49	54	69	74	
30	39	43	69	73	30	40	44	70	74	
40	30	34	70	74	40	31	35	71	75	

people as necessities; and electrical equipment is used in increasing quantities.

Chemistry supplies the materials—metals, plastics, textiles, colouring material, petrol, etc.—required for many of these amenities and necessities.

4. The increased efficiency of industrial processes.—New products are manufactured as substitutes for natural products. Some of these have very similar properties to the natural products, while others have special properties of their own. Synthetic rubbers, plastics, rayon, and vanillin are used respectively instead of natural rubber, wood and glass, natural silk, and vanilla, although their chemical nature is different. Chemists carry out research on the preparation and properties of these materials, and are concerned at every stage with increasing the efficiency of the industrial process to secure higher yields and purer and more useful materials. Further, chemists invent methods of using less fuel, they prevent unpleasant gases entering the air, and they suggest means of using waste products from industrial processes.

5. The reduction of dependence on local natural materials.—Synthetic substances such as sodium nitrate and camphor are made in a number of countries from commonly occurring materials, so that the monopolies formerly held by Chile and Formosa respectively have been broken.

Some non-material benefits

1. Chemistry has a cultural value.—Chemistry, as an essential major branch of Science, plays an important part in the development of moral and intellectual capacities. It must be emphasized that scientists, like artists and musicians, derive intellectual and aesthetic benefits from their activities. Further, no educated man can be considered cultured today unless he has a knowledge and appreciation of Chemistry and its applications. It is not suggested that Science should have any privilege over the Arts and Music, but that 'a society's heritage and contemporary progress in science is as integral a part of that society's culture as its music and literature and should be absorbed normally as part of a general education'.

2. Chemistry is international.—The facts and principles of Chemistry are shared, and new facts appear in Chemical Journals for the

benefit of people of all nationalities. The aims, laws and chemical symbols are the same for all countries, and many chemical problems have only been solved by the united efforts of chemists of different nationalities: e.g. combustion, the periodic classification and atomic structure.

3. *Chemistry helps to reduce superstition.*—A knowledge of Science, including Chemistry, helps to remove belief in quackery, superstition and witchcraft and to discourage the persistence and growth of undesirable human habits of conduct and health. Advertisements concerned with the facts and principles of Chemistry ought to be checked from time to time either by suitable chemical analysis or by the use of the scientific method.

4. *Science, including Chemistry, is a method.*—Scientific attitudes and habits of thought have important personal and social functions, and learning the facts of Chemistry ought to be considered as a means rather than an end. Science is a method, not a body of dogma.

The social implications

Today, more than in the past, emphasis is given by some men of science to the viewpoint that all branches of Science develop best when actively related to problems of the world's work. Some assert that pure Science only advances when the contemporary social structure is capable of making full use of its teaching, and when new problems are provided by the community. In short, the needs of the society create a particular demand. If the state, financiers and large firms benefit from research, then they in turn are prepared to finance it. It may be pointed out that there would be little need of spectacles if there were no printing, nor would telescopes and microscopes have been devised if glass lenses were not required for spectacles, nor would astronomy or bacteriology have developed without telescopes and microscopes respectively.

The social responsibilities.—Chemistry will be the profession of only a small, but important, minority of today's school children. It is, however, essential to develop an interest in Science, including Chemistry, in every intelligent citizen so that he may realize that his very existence depends on the control of Science and its discoveries. On the other hand, the trained chemist himself ought to develop a

social conscience. No longer should the politician and industrialist be left with the ultimate control of Chemistry and all that it involves, while the chemist stands by and disowns responsibility.

Pupils should realize that the special characteristic of human existence today is the dependence of modern civilization on Science. Man cannot control Science unless he is aware of its real nature, and has a proper knowledge of its aims and principles. Chemistry has advanced too rapidly in recent years for most people to appreciate its influence fully, and to apply it completely to improve the conditions of life and society, so the professional chemist has a special responsibility to the community.

It seems evident that economic self-sufficiency is impossible in any progressive country, and that necessities such as petrol, rubber, fuel, fertilizers and foodstuffs must be imported, wholly or in part, by most countries from elsewhere. Citizens must realize this, and be prepared also to learn by education and experience that the discoveries of Chemistry must be controlled for the general benefit of all mankind. World-wide problems in malnutrition, disease and unemployment remain to be solved. It is obviously undesirable that steel should be used to make tanks and guns rather than to construct bridges and houses, except when national survival is threatened by external aggression.

Finally, the control and proper utilization of chemical research and inventions—like that of all scientific inventions—is only possible when it is realized that the interests of humanity at large must be served.

CHAPTER II

Reasons for the Inclusion of Chemistry in the School Curriculum

The benefits derived from the study of Chemistry

The trained Chemistry teacher will be acquainted with the ideals and aims of his subject and of the scientific attitude and method, but many difficulties arise when he attempts to interpret them so that his pupils may be inspired with enthusiasm for such ideals. Indeed, the problem of discovering the best methods of training young pupils to appreciate, as far as possible, the principles and methods of any science cannot easily be solved.

For convenience, the chief educational advantages derived from studying Chemistry are tabulated below. As emphasized elsewhere, these advantages are shared with other branches of Science, and it is generally accepted that all pupils should study General Science in the first place.

1. Chemistry gives an essential background of knowledge for cultural development—it expands the pupil's knowledge of the universe and of his position in it; it helps in the appreciation and enjoyment of nature and life; it offers a basis for a proper and valuable use of increased leisure; and it stresses the need to take an active and intelligent share in the development of the community.

2. Chemistry gives many opportunities to foster the scientific method and discipline, since it trains the pupil to observe and think clearly and carefully. This training should whenever possible be applied to real and worthwhile problems affecting the personal life and thought of the pupil, so that such benefits may be transferred to his other activities.

3. Chemistry stresses the need to appreciate the meaning of scientific life, spirit and endeavour—open-mindedness, intellectual honesty, self-sacrifice and devotion—which ought to serve as ideals to the future citizen. Contributions made to the community through the efforts and achievements of chemists should be known to all.

citizens, since they are a distinctive feature of modern civilized existence.

4. Chemistry acquaints the pupil with a knowledge of chemical facts needed not only for many trades and professions, but also by all citizens, to enable them to lead happy, well-balanced and useful lives. Future citizens ought also to know of the possible influence of new chemical discoveries and should realize the need for proper control. It is therefore necessary to understand, as a minimum, the simpler words and definitions in Chemistry, the relationship between Chemistry and other fields of knowledge, and the elementary facts and principles of this subject, so that in later life the pupil may keep himself informed of important developments.

S. R. Powers has devised the following alternative form of setting out these aims to satisfy the major needs of the pupil. He classifies the needs of a scientific education from three standpoints:—

1. As a citizen, with certain civic and social duties and responsibilities.
2. As a worker, in duty bound to bear his share of the economic load.
3. As an individual, who must have varied non-vocational interests and pursuits if he wishes to lead a normal and well-balanced life.

The reader might consider re-allocating the preceding four aims under Powers's three headings, bearing in mind that the effective teaching of Chemistry ought to improve the student's health, his wise use of leisure, his ethical standards, his manipulative skill and his knowledge and fulfilment of duties as parent and citizen.

A chemist obtains first-hand information, to a great extent, from direct contact with materials, and is able to build up the subject-matter from facts which he obtains personally and can verify for himself. He repeats an experiment—a test carried out under certain known conditions—time after time in his search for a satisfactory explanation and he varies the experimental conditions to find the underlying relationship. He pays especial attention to the degree of accuracy and the methods of obtaining results. Indeed, many of his discoveries are due to long and patient measurement with accurate instruments. He discovers and formulates laws, and verifies his assumptions by studying a small number of isolated substances under precise conditions in his laboratory. In doing this he must

devise experiments to test his hypotheses and to deduce general principles.

The first steps in the scientific method of approaching a problem are inductive, since the pupil (a) perceives the problem, (b) collects and organizes relevant information and (c) forms a tentative hypothesis which he tests. He then makes, and in turn tests, other hypotheses using additional information, and he then selects the hypothesis which best fits the evidence available. Finally, and deductively, he applies the generalizations obtained from the hypothesis to specific cases. A hypothesis is thus a reasoned guess or deduction and is used to predict further results. If it correctly forecasts results which may be confirmed experimentally it is called a *theory*. A theory, however, still contains an element of doubt, but with modifications it may be the means of formulating a new law. A *law* is a well-confirmed statement of relationships based on experimental proof.

Practical Chemistry develops initiative and steadfast perseverance. Imagination is developed also as the chemist frames hypotheses and verifies them by experiment. The chemist learns to be cautious, to be impartial, to practise mental rectitude and to eliminate the personal element.

The knowledge which Chemistry ultimately adds to the world's store, unlike that afforded by many other subjects, is not built upon uncertain human opinions and generalizations influenced by changing fashions or by traditional taboos. Indeed the teacher should always bear in mind the paramount need to encourage the student to think critically, to make unbiased conclusions as a result of logical thinking, and to be precise and honest in his observations and recordings. As J. B. S. Haldane states, a major benefit of the study of Chemistry is the gradual spreading, among humanity as a whole, of the point of view that prevails among research workers. The scientific outlook of impartiality, the critical assessment of accepted opinions and the classification of all occurrences on the same emotional level, should influence conduct in our homes, and our attitude to the government of our own country, in the same way that it has affected our work, wars and hygienic conditions.

Transfer of training.—The relationship between scientific method and mental discipline introduces ideas on formal training. Mental

processes were once thought to depend on simple capacities called 'faculties'. It was argued that the teaching of Science was unnecessary because the same regard for logical thought and systematic work was inculcated as a mental discipline by the study of other subjects such as classics and mathematics. It was thought that the art of precise thinking and working, which could be derived from such study, would permeate the pupil's outlook and would affect his habits in every other sphere of study or action. These views are now considered by psychologists to be inaccurate. Habits of scientific thought and method are much better acquired by the study and practice of Science itself. There is no automatic transfer to any other subject or sphere of life (although Biology and Physics have similar techniques and subject-matter to Chemistry). It is likely, however, that specific abilities and character traits (notably persistence, industry and honesty) may be transferred. It should be clearly understood that Chemistry, as a branch of Science, is a method and a habit of thought; and that subject-matter, training in skills, and teaching technique should be selected accordingly, and should be well and closely linked with the pupil's emotions and common interests. Further, the pupil must deliberately be encouraged to use the scientific approach in solving everyday problems. Transfer of training is most likely to take place if this is consciously done and if similar facts, principles and ideals are considered together. The 'problem' or 'modified heuristic' approach appears to be particularly valuable when used together with realistic problems of everyday life.

The special application to teaching in schools

The above summary states the essential aims and ideals of Chemistry teaching.

It should be realized, however, that very few persons are in the fortunate position of the research worker, who is able to enjoy all the privileges of the man of Science. Advanced students may, and should be, in a favourable position to begin acquiring the attitude and tendencies of the trained chemist. Junior pupils, however, cannot be expected to appreciate the more mature principles of this science, though a well-designed course requiring the solution of simple problems may call forth, even at this early stage, the qualities of accuracy, caution and suspension of judgement.

Moreover, the teacher of Chemistry should have undergone a systematic training in Science and should have had some experience of research, being enabled thereby to inspire his pupils with the ideals of the research worker. The teacher's enthusiasm, his attitude to the subject, his effective demonstration methods and his learning should inspire the pupils with a thirst for chemical knowledge. And the greatest asset that the teacher can possess is enthusiasm.

The boy who takes with him from school an ideal of truth and of knowledge for its own sake and of the discipline which Science exacts, can play an important part in the world of the future. In addition, he has been given encouragement to advance further along the path upon which his feet have been set, a stimulus independent of the reward of fame or wealth.

By occasionally developing a topic historically, the teacher can give his pupils contact with the stream of thought which flows from the craft of the originators of the science to the well-organized scientific movement of today.

During the early stages of teaching, Chemistry pupils are influenced by the instincts of curiosity, collecting and constructiveness. These instincts can often be satisfied by the opportunities provided by the study of Chemistry. The spirit of inquiring into changes in the environment is developed. The desire to do things in order that something may happen appeals to the pupil and forms an excellent starting-point for sound experimental work. Opportunities are given to deal with realities which are not influenced by human beliefs and arguments. More obvious benefits obtained by the pupils from effective Chemistry teaching are care and skill in handling apparatus and materials, and the use of correct methods in obtaining accurate experimental results. Most boys and many girls are eager to begin the study of Chemistry, probably because of some of the reasons stated above. They look forward especially to the joys of working in a laboratory. Such a positive and definite initial enthusiasm for a subject is a decided asset, which must be fostered and developed. Although pupils are unable, at first, to appreciate the more subtle advantages of the subject, they soon realize its wealth of romance and its many applications in the ordinary affairs of life.

Teachers in North America and North Europe know of the pleasure obtained from the simple Chemistry cabinet and of the

many hours given to experiments with inexpensive home-made apparatus. As pupils often work at home under unfavourable conditions, the facilities provided by the school laboratory should mean that outstanding results are obtained. An additional testimony to the natural attractiveness of the subject is the popularity of school and class chemical societies. No one, after hearing the well-prepared lectures given by some pupils, can doubt that the subject has an appeal to youth.

The profession of Chemistry—with its many branches in industry and administration—affords excellent prospects to the boy with brains and slender means. A grounding in this science is also required in the training of doctors and nurses, pharmacists, agriculturalists and engineers.

Criticisms of Chemistry teaching. Answers to the criticisms

It is unnecessary to discuss here the general difficulties that every subject in the curriculum presents to individuals or groups of pupils who fail to grasp their meaning and main outlines. No mention will be made of adverse home conditions, ill health, physical defects, irregular attendance at school, incorrect classification in the school, dislike of a teacher's methods, and weakness in one subject having an adverse effect on another. Reference will be made here only to special difficulties which pupils appear to meet in studying Chemistry, and to criticisms made by educationalists and others.

The subject-matter and the technique of teaching Chemistry are criticized as outlined below. Whilst some of these criticisms are made without full knowledge of the facts, others must be constantly kept in mind by the teacher if Chemistry is to be well taught.

1. It is urged by some critics that the majority of school Science syllabuses are designed for the comparatively small number of brighter pupils who pass from school to universities, technical colleges and other institutions for higher education, and that the majority of pupils get little benefit, because the courses are incomplete or unsuitable. This criticism is often true. Many pupils suffer from the narrow and academic nature of their school Chemistry course, but the substitution of General Science for the individual subjects, Chemistry and Physics, with an appropriate change in teaching methods, may eventually provide a satisfactory remedy.

2. Examinations are justly blamed, since they certainly narrow the scope of school courses. It must not be forgotten, however, that examinations have their uses, and in many cases it is possible for a teacher to evolve suitable methods, or a variation in factual material, to suit the particular class under his charge. This influence can be seen in several text-books which have been specially written for boys and girls. The simplicity of the language, the interest of the constant reference to the pupil's environment, the ease and convenience of carrying out the laboratory instructions, and the inspiration of the writing, combine to form most helpful and stimulating books. On the other hand, other so-called popular books fail to benefit pupils who are just beginning Chemistry or General Science, because their authors are not acquainted with the best approach to the child's interests. The vicious circle of basing a new book on the contents of an old one still goes on: material which is suitable for a mature student is slightly modified and rearranged for the 'average' pupil in the 'average' school.

3. The methods of introducing Chemistry are also criticized. It has been urged that too much time is given to laboratory work and that the teaching of general principles has been neglected, and that, whereas Chemistry-teaching formerly neglected individual work, the present methods over-emphasize it. This may be true of a few schools, particularly those which use mechanical and unimaginative instruction cards or assignments. In such cases, a series of disjointed experiments may have little in common with the descriptive classwork. In the majority of schools, however, the practical work is carefully planned and rather more time is given to theoretical than practical work. The criticism that certain mechanical experiments are carried out by pupils to keep them busy is rarely true.

Teachers must, however, carefully consider the aims of practical work and the reasons for including particular experiments in the course. Such experiments should be omitted if they do not help (a) to develop the manipulative skill of the pupil, (b) to discover or rediscover new facts or principles; if (c) they cannot be completed in time or (d) do not give a clear conclusion or definite result. Teachers must also decide if an experiment should be done individually by groups of pupils or by teacher-demonstration (see Chapter VI).

4. Few teachers would agree with one writer who states that 'This

so-called Science which is placed upon the time-table is generally looked upon by the pupils as a series of trick lessons wherein magic plays a great part, spectacular phenomena alone interest, the innate love of discovery is chilled by research of which the importance is never made manifest. Science is never made a hobby. It is always a test. Numberless observations are insisted upon so that it may be discovered who may be fortunate enough to see the correct reading and get the nearest average.' While Art, Music and Cookery, he maintains, are taught by experts who emphasize their strong appeals, many Science teachers do not train their pupils in such devotion. 'Yet Science, that seeks to unfold the mysteries of everything around and within us, that seasons the desire to know the why and wherefore of all that we touch, see, feel or imagine, is left in the hands of people who never seek any new way to make discovery a delight, or invest ordinary reactions in everyday life with the charm of far-reaching deduction and fostering a hunger for further research.' If a reply is necessary to these sweeping criticisms, it is hoped that sections of this book will supply it.

5. The lack of correlation with the kindred subjects Physics, Biology and Mathematics, as well as with Geography, History and English, forms the basis of another criticism. Chemistry certainly loses some of its effectiveness if there is no correlation with other subjects. Many of the pupils' difficulties would be removed if syllabuses were designed to avoid unnecessary repetition, to develop kindred topics from different angles at the same time, and to provide the necessary foundation and background. Specialization in one or two subjects is often less purposeful and effective than the less ambitious programme attempted in schools where Science is not broken up into its separate branches.

It should be noted that there has been a considerable extension in the teaching of General Science rather than of the separate subjects Physics, Chemistry and Biology, both in Great Britain and the U.S.A. It is not intended here to discuss the relative merits and demerits of General Science.¹

¹ Readers will find such information in (a) Vol. VII of the present series, (b) *The Teaching of General Science* (1947) (Murray), (c) National Society for the Study of Education, Thirty-first Year-book, Part I, 'A Programme for Teaching Science', and other books.

6. Another criticism will be mentioned here and dealt with in more detail in Chapter X, namely that Chemistry is difficult to learn because of its extensive new vocabulary and its highly specialized language. Teachers must realize this difficulty and be careful to grade their own language so that chemical terms are introduced only when they fulfil an indispensable function. Further, teachers should be sympathetic to young pupils who have special difficulties in spelling and pronunciation. In some schools there is too much emphasis on learning Chemistry by memory, with little attempt to teach the appreciation of Chemistry as a method.

7. Other critics assert that the maximum educational benefits are not obtained from the teaching of Chemistry, and that little transfer occurs in the application of chemical knowledge to solving problems met in the kitchen, garden and home, by men and women who learnt Chemistry at school; that especially noticeable is the lack of clear logical thinking applied to communal and world problems.

8. The basis of another criticism is that Chemistry appeals to the pupil's brain and not to his heart, since it has no basis in the emotions nor in human experience. Such alleged disadvantages, for most pupils, may be obviated to some extent by treating the matter historically. In junior work, accounts of the lives and work of well-known investigators—Priestley, Lavoisier, Faraday and Dalton—and the development of knowledge about air and water provide a sound historical background.

The tendency to overburden the teaching material with an excess of facts is avoided by referring to the human side of Chemistry. A course which is continually alluding to the local industries, the geology of the pupils' own neighbourhood, and the occupations of the pupils' parents, must become tinged with human experience. In more advanced work it is possible to deal with the spirit and method of Science and to illustrate by definite historical examples, and by suitable experiments, the relative functions of hypotheses, theories and laws. Class discussion and detailed preparation for long essays—especially valuable at the end of a term—are a useful method of approach. Suitable subjects are:—the competition between synthetic and natural products, the influence of Chemistry on the community, atomic energy, benefits derived from chemical discoveries, the

control of chemical knowledge, radioactivity, recent advances in medicine and biochemistry.

9. Finally, a reference to the literature of General Science will bring the pupil into contact with the historical accounts of the discoveries and views of such men as those mentioned above. Accounts of the research work and personalities of such as the Curies, Pasteur, Davy, Priestley and Lister are an inspiration to girls as well as boys. Older pupils will, depending on their own interests and opportunities and the guidance given, read biographies and autobiographies. The emotional life at the adolescent period is particularly strong, and contact with fine and noble lives is especially valuable. Further, the historical works of writers such as Singer, Sherwood Taylor, Holmyard, and the original writings of the early chemists (available in the Alembic Club Reprints), help pupils to discover that Chemistry, as a branch of Science, has its own limitations and that its methods can only be applied to certain fields in which experiments and measurements are practicable. Aspects of knowledge and life concerned with art, beauty and opinion are beyond its scope.

Among later authors, the pupil may gain inspiration from the works of Charles Darwin, Thomas Henry Huxley (whose essays are models of clarity and sound logic), J. Clerk Maxwell, John Tyndall, Frederick Soddy and J. J. Thomson.¹

¹ The popular Christmas Lectures of the Royal Institution of Great Britain are very suitable for adolescents. They are printed and published.

CHAPTER III

Syllabuses in Chemistry

(A) For Junior Students

The framing of an elementary Chemistry syllabus

Difficulties encountered by young teachers. — Most young teachers are at a distinct disadvantage when they have to draw up a syllabus. They spend insufficient time in the school or college where they carry out their teaching practice to appreciate the arrangement of its syllabus, and model syllabuses are rarely drawn up for students and discussed by practical teachers while they are in training colleges or departments of education. Young teachers are seldom familiar with the best type of text-book. They may also lack familiarity with the external examination which influences the syllabus of the institution to which they have been appointed, and they may not realize the limitations of the average school laboratory.

The main aims in building up a syllabus. — The chief aims in building up a syllabus are to:

(a) Include a maximum amount of subject-matter selected on educational grounds to develop the scientific attitude towards solving problems and to satisfy the real needs of the pupil. Examination syllabuses still retain material which must be included in every Chemistry course, although it is not always suited to individual requirements.

(b) Realize the limitations of the average pupil in assimilating facts, and yet appreciate the outstanding ability of clever pupils.

(c) Note the necessity for constant recapitulation.

(d) Guard against excessive influence by university text-books, except for a few very advanced students.

(e) Explore the possibilities of using local material.

(f) Relate the teaching to everyday Chemistry and stress economic and social implications.

(g) Grade the material for parallel classes of different ability.

(h) Avoid discussing theoretical principles in the early lessons,

giving instead definite lessons on single subjects or a connected series of subjects. (Teach method rather than subject-matter.)

(i) Take into account the age at which the pupil starts learning Chemistry, and ensure that he can assimilate the ideas presented.

(j) Appreciate the outlook of the pupil so that his interests, limitations, difficulties and hopes are understood.

(k) Grade the material so that it is introduced at the exact time it is required. (Make sure that classes of differing ability are provided with material of suitable difficulty and that the methods used are appropriate.)

Other considerations.—It is important to ensure that the Chemistry syllabus for advanced students and the Chemistry section of the General Science course are drawn up for:

1. The majority of pupils who need a self-contained course in general Chemistry.

2. The specialist who requires a systematic grounding of chemical facts and methods in preparation for a university or technical college course.

No syllabus should be too rigid, as references must constantly be made to national, local and topical events or phenomena. Allowance should also be made for loss of time for any school function which may interfere repeatedly with the classwork or homework, and for illness.

It is doubtful if an excessively logical approach is advisable in designing a syllabus in elementary Chemistry. Rather ought the teacher to base much of the syllabus on suitable live problems which the pupil can solve. In the first and second years the problems should be straightforward, so that a clear conclusion is reached:—air is necessary for burning; burning and breathing are examples of combustion; air is made up of four-fifths nitrogen and one-fifth oxygen; oxygen is the active gas in air. Later the pupil will obtain clear experimental evidence to verify the chemical laws. Applications of the chemical principle in the activities of the local community may then be considered. The last step can be a discussion of the effects of the principle in human society, and of the scientific attitude and spirit.

In the first year of the four years' course (pages 25–6) the pupils build up a knowledge of Chemistry from laboratory experiments.

This is supplemented by class discussion and to some extent by reference to a text-book.

The necessary theoretical work in each year runs parallel with the practical lessons.

It should be understood that occasionally more than one experiment is performed to stress a particular principle. It must also be possible to spend a relatively longer period on one exercise if an experiment is carried out badly and poor results are obtained. Again, it often happens that more time than was anticipated must be devoted to emphasizing certain theoretical questions.

In the final year, a rearrangement of the normal procedure may be necessary, and laboratory work may not always coincide with the theoretical and descriptive parts of the syllabus. This change of routine is caused either by the use of more complicated apparatus (the supply of which is limited and which can therefore only be used by a few pupils at a time), or by the need for revision of certain parts of the theoretical work. An attempt should also be made to develop the pupils' initiative by setting miscellaneous practical problems which are not connected with the theoretical lessons. The syllabus for the final year might be arranged so that the pupils write the notes on their practical and theoretical work directly into their exercise books. Then the homework could be devoted to answering test questions and to revising from text-books and notes. In practical lessons the teacher should have more opportunity of discussing individual difficulties than he had in the earlier years. During the course of the experiments, and while the notes are being written, he should point out errors to individual pupils, commend outstanding work, and make himself more familiar with the opinions of each member of the class.

Enthusiastic teachers of Chemistry always introduce their own ideas and stress the particular schemes of work which they consider important. Teachers interested in industry, biology or geology should certainly direct the attention of their pupils to the chemical aspects of these subjects. Their knowledge and enthusiasm will make the lessons both instructive and inspiring. Finally, the teacher must always keep in mind the external examinations, as these influence to a large extent the whole of the syllabus.

Notes on the Chemistry section of a General Science course (see p. 25)

It is suggested that the following topics should be included in the syllabus for a four years' course in General Science for boys and girls, aged approximately 13-16 years. It should be clearly understood, however, that General Science must be taught as a whole and not as the separate subjects Physics, Biology, Chemistry, etc. The subject should appear in the time-table as General Science and ought, preferably, to be taught by one teacher rather than by a physicist, biologist and chemist in turn.

Teachers unfamiliar with General Science syllabuses and who have previously prepared pupils for Chemistry examinations might note essential differences. 'It is expected that the scientific principles mentioned in the syllabus will be studied in relation to their practical applications in everyday life'; 'emphasis should be placed on the foundation of scientific knowledge on observation and experiment'; 'the influence of scientific thought and achievement on human experience should be illustrated by example'. All three principles are accepted by all Science teachers.

Much of the approach is qualitative, but quantitative methods are essential to illustrate a number of scientific principles. Demonstrations often replace individual and group experiments, and the general treatment is less detailed and includes less chemical theory than Chemistry taught as a separate subject.

Usually the General Science syllabus excludes the following topics, but, if two examination papers are taken, they may be included: commercial preparations of hydrogen, oxygen, water-gas and producer gas; the contact and lead-chamber processes for sulphuric acid and the Haber process for ammonia; outline treatment of phosphorus and silicon and their compounds; ozone and hydrogen peroxide; the halogens other than chlorine; nitrous oxide; the electrolytic preparations of zinc and aluminium; hydrogen sulphide and its salts; solubility curves; a little theory connected with the laws of Gay Lussac and Avogadro; atomic weights, valency, molecular weights. Thermal and ionic dissociation, and normal solutions are also included, and equivalents are limited to the displacement of hydrogen and combination with oxygen. Mathematical problems and equations are confined to simple reactions.

On the other hand, the syllabus is often enlarged by the inclusion

of Chemistry connected with other branches of Science: for example, osmosis, diffusion; nature of soils, culture experiments and fertilizers; biochemistry and the science of health, including vitamins, nutrition and preservation of food; carbohydrates, fats and ethyl alcohol. Reference must, however, be made to the particular syllabus used by the pupils and to volume VII of this series.

Such factors as size of class determine the time to be given to each section of the syllabus. For example, in the section on water of crystallization the suggested material is covered in one week if no quantitative analysis is attempted. It may be impossible to include such an experiment if thirty-five pupils are to be taught in a small laboratory with a limited number of balances. Under more favourable circumstances the pupils should certainly carry out such work and spend an extra lesson on this branch of Chemistry.

In the following course, (D) before a heading, or sub-heading, indicates that the experiment is best demonstrated by the teacher. Again, laboratory conditions should be considered. It is, for example, dangerous to allow pupils to burn hydrogen at a jet to synthesize water, unless they are carefully supervised; hydrogen sulphide cannot be prepared by all the pupils in a large class unless a large number of fume-cupboards are provided or small-scale apparatus is used and special precautions are taken; and water cannot be electrolysed by all the pupils unless there is an abnormally large stock of suitable apparatus.

It should be realized that a practical lesson may occasionally be arranged so that the pupils prepare a gas, such as hydrogen chloride or chlorine, in a test-tube fitted with a delivery tube. Thus, they carry out most of the tests on a small scale in the first part of the lesson. Later, the teacher demonstrates the large-scale preparation, and by means of more complicated apparatus and his superior skill is able to show the more unusual properties of the gas or to repeat any unsatisfactory individual experiment.

Basis of the Chemistry section of a General Science course

First and Second Years

1. *Introduction to methods of laboratory organization, marking notation—Chemistry as a hobby—summary of history of Chemistry.*

2. *The Bunsen burner*—different flames, cones and structure.
3. *Solution*—definitions—testing solubilities of common substances—solvents other than water.

The separation of a soluble and an insoluble substance—the handling of apparatus—quantitative aspects—purification of rock-salt or sea-salt.

Solubility—potassium nitrate in water—conditions for obtaining good crystals.

4. *Burning and the study of air*—heating substances in the presence and absence of air—to find if magnesium changes in weight on burning—heating in a crucible—introduction to the law of constant composition.

Burning substances in a limited amount of air—burning tapers, candle, (D) sulphur and (D) phosphorus under various sized jars standing on ground glass and in water—the composition of air—the rusting of iron—oxygen and nitrogen.

5. *To try to obtain oxygen from oxides of metals and other substances by heating*—testing for oxygen—Lavoisier's and Priestley's work.—*The preparation of oxygen*—burning substances in it—the types of oxide formed.

6. Bases and alkalis—experiments with wood ashes, soap powders, basic oxides and hydroxides made the previous week—the preparation of a chart contrasting and comparing commoner metallic oxides and hydroxides—experiments with indicators.

7. *Acids*—organic and inorganic—similarities and differences of the concentrated and dilute acids.

8. Salts—neutralization—use of pipette and burette—preparation of a salt from a hydroxide—sodium chloride, ammonium chloride, potassium sulphate, etc., made by various members of the class.

The preparation of a salt from an oxide—copper sulphate, lead chloride, magnesium sulphate, zinc sulphate—conditions necessary to obtain good crystals.

The preparation of a salt from a carbonate—potassium nitrate. Reference to other methods, such as the use of a metal—summary of all preparations in a chart.

The action of hot and cold dilute acids on metals—the identification of hydrogen.

Practical tests to identify unknown metals—the introduction of

acetic acid and other organic acids, and the application of previous knowledge.

9. *The preparation and properties of hydrogen*—(D) the burning of hydrogen—(D) the electrolysis of water—(D) the action of metals on water—decomposition with cold water; with steam—metals with no action—water is a compound.

Third and Fourth Years

1. *Investigation of the different forms of calcium carbonate*—snail-shells, sea-shells and egg-shells; chalk, limestone, marble, calcite and pearls—contrast and comparison—carbon dioxide.

The preparation and properties of carbon dioxide—its occurrence in Nature. The effect of heat on calcium carbonate—lime, slaked lime, lime-water—lime-kilns—the carbon cycle in Nature—mortar, cement, the weathering of rocks, soil.

2. *The natural waters*—distillation—town water supply.

Further consideration of the composition of air—(D) preparation of nitrogen—presence of carbon dioxide and water vapour in air—air is a mixture.

The solubility of air in water—analysis and comparison with atmospheric air.

The amount of dissolved solids in river- or sea-water—the solubility of potassium nitrate in water—solubility curve.

To find which of the following crystallized substances have water combined with them: sodium chloride, copper sulphate, sodium carbonate, etc.—water of crystallization—deliquescence and efflorescence—applications, quantitative aspect.

The hardness of water—soap solutions with distilled-, rain-, sea-, tap- and river-waters—reasons for temporary and permanent hardness—the connexion with carbon dioxide—softening.

3. *The study of sulphur*, its uses—(D) the synthesis of sulphur dioxide, (D) its preparation and conversion to sulphur trioxide—sulphuric acid, (D) its preparation by the contact process—properties.

4. *Sodium chloride*, sea-water—hydrogen chloride and its action on different types of oxides—the preparation of chlorine, its properties and uses—(D) the electrolysis of hydrochloric acid.

5. *The study of carbon*—allotropes, chart of comparison, tests for allotropy—the preparation of metals from their ores, reduction

(introduced simply), experiments with compounds of lead, iron and copper—carbon monoxide, the chemistry of a red-hot charcoal fire, the manufacture of coal-gas, combustion—comparison of carbon monoxide, carbon dioxide and hydrogen.

6. *Reduction and oxidation*; examples and tests—different types of oxides.

7. *Potassium nitrate*, its occurrence—nitric acid, its preparation and properties—decomposition.

8. *Ammonium chloride, ammonia*—fertilizers, the fixation of nitrogen, the nitrogen cycle in nature, connexion with plant life.

9. *The measurement of the volume of gas liberated in a chemical action*—equivalent, measurement by displacement of hydrogen—synthesis and reduction of oxides.

10. *The electrolysis of solutions of salts and acids*—links with electricity.

11. *Metals*—the extraction of iron, the manufacture of steel—important metals and their more important compounds: lead, copper and calcium—important sodium compounds: sodium hydroxide, sodium carbonate, sodium bicarbonate—differences between metals and non-metals.

Links with the teaching of geology and geography.

12. (D) *Physical and chemical changes*—many experiments and references to previous experiments—definitions and summaries. Experiments illustrating the differences between a compound and a mixture—examination in turn of properties of sulphur, iron and their mixture—heating the mixture—the compound, its properties—definitions and other examples of each class.

The law of conservation of mass—spectacular precipitation experiment—(D) phosphorus and match in flask—burning candle—historical references—enunciation of the law.

The atomic theory—history—atom—molecule—illustration by models—symbols, formulae, valency, equations and a summary of past work by means of equations—links with diet and calories.

13. *Organic Chemistry*—a simple treatment of starch, sugars, proteins, fats, vitamins, as required for a background knowledge in health education and biology.

Features of the syllabus.—1. In the first lesson, a summary of the

bistory of Chemistry to the time of Robert Boyle brings the pupil up to the period of the study of the atmosphere and the beginnings of modern Chemistry. The pupil's own experiments begin from this stage. The account of the early pioneers introduces the pupil to the human side of Chemistry and to its wealth of romance.

2. The early lessons give plenty of opportunity for gradually acquiring familiarity with chemical apparatus and technique.

3. Burning and the study of air introduce a group of connected lessons with an inspiring historical background, and thus lessons on breathing, oxygen, oxides, alkalis, acids and salts can be given systematically.

4. Pupils become familiar with elementary facts about air, and their knowledge is extended in later years by comparing and contrasting these results with the analysis of air dissolved in water. Oxygen and nitrogen are again dealt with whenever possible under sub-headings such as peroxides, oxidation, 'fixation' of nitrogen, ammonia, nitrates and the oxides of nitrogen.

5. The mineral acids and common bases are discussed as a group in the first year and treated in detail as individuals later.

6. Elements, mixtures, compounds, and physical and chemical changes, are not treated in detail until the pupils have a working knowledge of each type. Every opportunity should be taken to use these terms, as when dealing with such statements as: 'air is a mixture', 'water is a compound'.

7. The law of constant composition is introduced incidentally in the first year when burning magnesium and when heating mercuric oxide. It is considered in detail later, when volumetric analysis and the preparation and reduction of copper oxide are discussed.

8. The syllabus is framed to give the pupils only broad outlines in the first year. In subsequent years, these outlines are filled in and the subjects treated from a more mature point of view. For example, the use of pipettes and burettes to prepare common salt is followed by a more detailed treatment when volumetric analysis is being taught. Carbon dioxide is first studied in connexion with combustion, later in connexion with calcium carbonate, and finally when its properties are compared and contrasted with carbon monoxide and with sulphur dioxide. The scattered information on solubility is collected

and treated systematically when the experimental work is discussed, and a solubility curve is plotted from class results.

9. Most of the mathematical parts of the syllabus are treated in the final year. Pupils then have less difficulty with Mathematics and equations. If pupils are proficient in Mathematics this numerical work can be included earlier.

10. The syllabus is framed to suit the average school. Few of the experiments suggested require expensive apparatus. The scope of the sub-divisions permits a careful balance of individual work and demonstrations.

11. The subjects allow full advantage to be taken of the heuristic, Dalton and problem methods of teaching Science (see pages 58, 63, 122, 239). Several experiments require group work, while others require reference to, and repetition of, historical experiments.

12. Several of the experiments in each year's course may be quantitative, but too much tedious weighing should be avoided.

13. The study of the elements and their compounds, treated either in the order of the periodic table or in groups of oxides, chlorides and sulphates, is considered too advanced for juniors.

Other basic principles

The basis of the method of selecting material is dealt with above, but it is advisable to consider other criteria. The scope of Chemistry, even at the junior stage, is limitless, and the number and type of experiments which might be carried out are so great that it is easy to overlook the basic syllabus. The enthusiastic teacher using his own special abilities and knowledge ought to simplify the syllabus whenever possible and to omit whole sections which do not appear to serve specific educational purposes. In other words it must be stressed that the technique and material should be psychologically and individually sound and essential at the particular stage of the pupil's career. The laboratory approach must be realistic and practicable, and the information obtained directly or indirectly must be used for the benefit of the individual and the community.

Certain questions must influence the teacher in deciding on the facts and principles to be included:—

1. Is out-of-date information being used? The teacher should keep

up to date with the productioo figures of different processes such as: (a) the cootact and lead-chamber processes; (b) hydrochloric acid manufacture—the synthetic method and that from common salt; (c) nitric acid—the Haber synthetic method from sodium nitrate, and the obsolete Birkeland and Eyde processes; and (d) the different uses of metals and their alloys.

2. Are principles and facts being learnt which are essentially valuable and inter-related rather than isolated and of doubtful value? For example, some teachers omit, in the early stages, detailed treatment of the oxides of nitrogen, physical changes which occur on heating sulphur, the phlogiston theory, the preparation of nitrogen from ammonium nitrite, and detailed methods of drying and collecting gases, such as by displacement of mercury. Certainly the pupil should be trained to use reference books to find out values of physical constants and other facts, rather than to commit such details to memory.

3. Must facts be learnt only to be discarded or amended at a later date? Most teachers consider that a pupil should be taught just as much as he can understand. Later, with increased knowledge and maturity, he can modify his ideas. It is quite satisfactory for a junior to learn that an atom is chemically indivisible and to learn later about electrons, protons, neutrons, etc. At an early stage he learns that air is necessary for breathing, later he modifies the statement and substitutes oxygen for air. Similarly, he first learns that air is made up of $\frac{1}{4}$ nitrogen and $\frac{3}{4}$ oxygen and later learns the more precise figures 21.0 per cent. of oxygen and 78.06 per cent. of nitrogen by volume and 0.94 per cent. of argon with traces of other gases.

4. Ought certain experiments to be more in accordance with commercial practice? Some chemists assert that many experiments such as the preparation of oxygen from heated potassium chlorate and manganese dioxide, and of sulphur dioxide from copper and concentrated sulphuric acid, have no relation to industrial Chemistry and should therefore be omitted. They consider that cylinders of oxygen and siphons of liquid sulphur dioxide should be used to supply these gases. In very elementary Chemistry and especially in General Science courses the criticism is justifiable. Pupils, however, who study Chemistry seriously, require knowledge of such experiments in later years for sound educational reasons.

The pupils should from time to time be told that the usual apparatus in the laboratory is specially designed for teaching purposes. In general, more advanced students and research workers use the same type of apparatus. Glass vessels can easily be cleaned, can be heated, are little affected by most chemicals and are transparent. Glass can be fashioned into many convenient shapes suitable for experiments; it is cheaper than, and its physical properties are preferable to those of, other materials. Industrial chemical plants, however, are made of different materials, including metals, and these are sometimes lined, for example, with silica. There are many reasons, including cost, strength and the different chemical and physical properties required, for not using glass in manufacturing processes.

(B) For Advanced Students

Teaching Chemistry to more advanced students

The preparation of lessons.—The young teacher should experience much less difficulty in recalling the facts, principles and standards of more advanced Chemistry. By the time the students reach this stage, they should have passed through a well-organized course in the laboratory, have developed sound habits of reading and be used to questioning unsupported statements rather than accepting them. In the advanced course, students continue this training, and should gradually acquire a more mature point of view. As the student is specializing in Chemistry, he will be expected to give much more time to his preparation and home studies, thereby amplifying the basic principles learnt in the laboratory. Several written exercises should be done each week, and wide reading should provide him with different aspects of the subjects under discussion. He should make many more summaries than in the earlier years. An increasing amount of time and a smaller size of class enable students to come into more direct personal contact with the teacher. More attention should be given to the rate at which individual students carry out experiments.

It is suggested that each pupil should be supplied at an early stage with a copy of the syllabus of the examination for which he is being prepared, and also of the order of introducing each section during the

year in which he is studying. Much waste of time is avoided if the advanced student clearly understands what topic is next to be introduced, and how far he is expected to study it both practically and theoretically.

In classwork, lessons may occasionally approximate to lectures, but the teacher should distinguish between imparting facts and teaching general principles.

Methods of studying.—The teacher should be aware of the different methods of giving a theoretical lesson and of their relative merits. It is, for example, a mistake to adopt the methods of a lecturer rather than a teacher, nor must the student be expected to take down endless notes lesson after lesson and to re-copy these later. The teacher must, in particular, consider the functions of text-books, library books and laboratory work in relation to his own teaching. He should strive for suitable varieties of approach, and should secure the active co-operation of the students.

Alternative approaches are:—

1. Discussion and lecture method—the teacher outlines the subject in general terms, dictates important generalizations and definitions, and either writes them out on the blackboard or gives the students typewritten 'duplicated' copies. Pupils then read prescribed pages in their text-books and library books and write out their own notes. This is followed by discussion.

2. Pupils first read sections of their text-book and library books, having been supplied with copies of the syllabus, and then carry out suitable laboratory work. Next, in classwork, the teacher summarizes the main points, asks questions, and explains difficult parts. Finally the student makes his own notes.

3. A suitable text-book is used as the basis of a lesson, the teacher emphasizes particular points, and the student asks questions. No notes are taken, but the pupils work through questions in the text, using further reference books from the library. In addition the teacher supplies historical facts and biographical, topical and local illustrative material to supplement the essential basic facts and principles found in the text-books.

In all three cases diagrams, charts, demonstrations, experiments and film strips are used when required to illustrate certain points.

Written and verbal tests, lectures by students, and visits to works supply variety of approach. In practice it is difficult to distinguish between the methods described, since a combination of all three may be used with advantage.

Lessons or lectures, based on the teacher's old university lecture-notes, should not be given to students. It may be a temptation to use these, but it must be remembered that they have often been prepared by a university lecturer who may be out of touch with school work, and who, in any case, has not designed his lectures for school conditions. It is better to write one's own notes, basing them on the books of authoritative teachers who write for students aged 16-19. The notes should concentrate on general principles, include clear, exact definitions, refer to illustrations and contain many worked mathematical problems. Unnecessary detail should be avoided. The subject-matter should be in correct perspective with the previous years' work, and should be specially arranged to fit in with existing conditions.

From time to time, new text-books and authoritative works of scientific importance should provide the teacher with more up-to-date details on manufacturing methods, the preparation of new compounds, recent applications of Chemistry and the latest ideas in theoretical Chemistry.

It is a difficult matter to give advice on the organization of the subject-matter of an advanced course, since it may have to be arranged for differing types of pupil. The course may be of normal length, in preparation for an examination as a main or a subsidiary subject; or it may have to be more general, for the benefit of pupils who will leave school at the end of the first year. The teacher may not be able to use the arrangement he prefers, as the first- and second-year students have often to be taken together. In this case, students can be grouped without much trouble for practical work, but it is more difficult to arrange the theoretical work.

One method frequently used in small schools is to divide a two-year course into approximately equal parts, so that first-year and second-year students study, for example, Inorganic and General Chemistry the first year, and Organic and Physical Chemistry the following year. Such a solution is by no means ideal, but with smaller numbers of advanced students there are few alternatives. Occasion-

ally, when one group is carrying out practical work or answering written questions, special lessons may be given to the other group, or pupils may be given individual attention and help.

Pupils who spend three or four years on the course provide further complications. These pupils, in particular, should supplement their text-book knowledge: e.g. by the occasional consultation of original papers, annual reports of chemical societies, monographs, and reference books. By contact with the Chemistry of the research worker the students should be inspired to high ideals, and their own laboratory work should, in consequence, be of the nature of true research. It is assumed that the teacher will arrange the teaching periods, probably of seven or eight lessons per week, to suit his own special conditions, but three periods at least should be spent in the laboratory.

The student beginning the serious study of Chemistry at the age of 16-17 will usually have studied the subject for three or four years, but will have little or no knowledge of Organic Chemistry, and sometimes little laboratory experience. The author believes that it is advisable to study the branches of advanced Chemistry in the following order, and for the practical work in general to keep pace with the theory. The headings are amplified later in this chapter.

1. Methods of studying Chemistry—advice to students on different methods—note-taking—number of hours per week for individual study—how to carry out advanced practical work—times when individual practical books and homework will be handed in for marking—how library books are to be obtained and used, etc.

2. History of Chemistry—scientific method—revision of laws—electromotive force (or electrochemical) series of activity—periodic classification, groups I and VII.

3. Qualitative analysis—group tables and principles of Physical Chemistry.

4. Aliphatic Organic Chemistry.

5. Physical Chemistry.

6. Volumetric and gravimetric analysis.

7. Completion of Inorganic Chemistry syllabus.

8. Completion of Physical Chemistry syllabus.

9. Aromatic Organic Chemistry, and completion of syllabus.

10. Revision.

Other teachers prefer a complete change from the methods used in the General Science course, and concentrate the early work exclusively either on Organic Chemistry or on qualitative analysis. Some teachers divide the time so that sections of Inorganic and Organic Chemistry are dealt with each week, but the author feels that this treatment becomes insufficiently detailed, and that concentration for several weeks on one single section yields the best results.

The basis of courses in Inorganic, General and Physical Chemistry.—At this stage the student is acquainted with a fairly wide number of facts of limited range. This section of Chemistry is best prefaced by discussion on the methods of Science and the attitude of the man of Science. Examples from earlier knowledge should be amplified to illustrate the meaning of hypothesis, theory and law. The student should now be receiving direct training in the methods of Science. He should be expected to profit from his study of Chemistry by developing his critical ability, and by acquiring skills to solve problems both in pure Chemistry and in connexion with life and industry.

The methods of determining equivalents should be treated in detail, the various laws reviewed, and molecular and atomic weight determinations discussed. It is worth while treating these topics in as broad a way as possible. The examples should include organic substances as well as inorganic. In fact, whenever possible the pupil should be made to realize that Inorganic, Physical and Organic Chemistry have much in common. The divisions are made for convenience, and are therefore artificial. The other topics in Physical Chemistry are treated both practically and theoretically.

The treatment of the elements and their compounds should be based on the periodic classification and the electrochemical series. It is necessary for the teacher to explain thoroughly the principles of the periodic classification. Large charts of Mendeleeff's table and of the modified Bohr scheme should be on view. The teacher should outline the historical development, the main features and uses of the classification, the electronic structure of the atom and, depending on the ability of his class, radioactivity, the discovery of new elements, isotopes, heavy water and atomic energy. From time to time all these sub-headings will be referred to again as different elements are dealt with in more detail.

After this general introduction full discussion may centre on each element in group I of the periodic table, so that the pupil will clearly understand the order of treatment and the relative importance of the various compounds of each element. Numerous generalizations associated with the table and the gradation of properties in each group should be given.

Thus, acidity or electronegative properties increase in passing from the left-hand to the right-hand side of the periodic classification and vertically decrease with increasing atomic numbers; lithium has certain resemblances to magnesium, beryllium to aluminium, and boron to silicon; the valency of an element bears a definite relationship to its group number.

Next, the properties of the members of one homologous series of organic compounds should be contrasted and compared with those of one group. Much of the information on the preparation and properties of the elements and their compounds can then be summarized from good school text-books by the pupils themselves.

The order of dealing with the elements is usually IA, IB, IIA, etc., in order, but a useful alternative is group IA, then group VIIIB, because the alkali metals and halogens supply useful material illustrative of typical properties of metals and non-metals; they show excellent gradations in properties, and illustrate most of the chemical principles required at this stage.

A reasonable amount of abbreviation should be allowed, and training should be given in the planning of notes. Useful generalizations, which apply particularly to the elements and compounds studied, will occur to the teacher.

Simple generalizations are that:—ammonium salts give off ammonia with alkalis; carbonates, nitrates and hydroxides of the heavy metals (e.g. lead, iron, zinc) form oxides on heating; all carbonates give carbon dioxide with acids; insoluble chlorides are silver, mercurous mercury, and lead; insoluble sulphates are barium and lead; sodium and potassium bicarbonates are the only stable bicarbonates; calcium hydroxide and hydrated sodium sulphate and most gases are less soluble in hot than cold water. Unusual facts are that hydrofluoric acid is a solvent for glass, and ammonia is the only alkaline inorganic gas. Some of these generalizations may be modified later as the students' knowledge increases.

Another example is the economic need for chemicals to be manufactured from comparatively common materials by simple methods. This is instanced in the Haber, contact and lead-chamber processes, electrolysis of salts, syntheses of organic compounds from substances such as carbon dioxide, hydrogen, coal and coal-tar. Further, students might note generalizations such as: the rule that non-metals usually do not form basic oxides, while metals do; a metal is least basic, or most acidic, in its highest valency state (non-metallic oxides are usually acidic, i.e. acid anhydrides); only transition elements have coloured salts and have a valency variable by single units (except indium and gallium), while other metals have valencies which do not vary or which differ by two units; among the metals, only the alkali metals, alkaline-earth metals, zinc, cadmium and aluminium have a fixed valency; the higher the valency state of a metal the more readily are its salts hydrolysed; all deliquescent salts are soluble in alcohol (except potassium carbonate), all others (except mercuric chloride) are insoluble in alcohol; halides of the mono-valent metals (except the alkali metals) are sparingly soluble in water. Students must be trained to avoid making indefinite and incomplete statements in their answers. For example, when writing 'sulphur is insoluble'—the solvent must be stated; 'the solubility of sodium chloride is 35.5'—the temperature and the units must be given; 'zinc and concentrated nitric acid give nitrogen peroxide'—more details are required on the probable formation of other oxides of nitrogen, ammonia, zinc nitrate, etc. Many other reactions proceed under certain conditions only, and unless they are specified, the statement is incorrect. Therefore, an advanced pupil should look for details of the physical state of the reactants, acidity, amounts, temperature, pressure, presence of air, catalyst, sunlight, the nature of main or side reactions, etc.

If a student has a flair for a certain branch of Science, or is definitely preparing for a particular career, it may be advisable to allow him to spend extra time in these directions. A pupil may wish to use the microscope for certain tests, or may be interested in Biology or in special branches of analytical Chemistry. He or she may wish, having been promised a post as a pharmaceutical chemist, to do work on the Chemistry of medicinal materials. Little, if any, educational value is lost by a slight bias towards this kind of work.

The basis of a course in Inorganic Chemistry.—Many advanced students find Inorganic Chemistry the most difficult branch of Chemistry because of its large number of apparently disconnected facts. The periodic classification and the electrochemical series are acknowledged to be the best methods of classification for summarizing and systematizing these facts, but neither scheme can be fully appreciated by the student at this stage. Other methods are therefore used. The occurrence, methods of extraction, and uses of the common metals may be dealt with in broad outline under such headings as (i) occurrence free in nature; (ii) chief ores; (iii) extraction by electrolysis; (iv) extraction by reduction. Much repetition of treatment is thus avoided, and links with the electrochemical series may be stressed.

Again, the metals may be dealt with in groups under the following headings:—Oxides, hydroxides, carbonates, sulphates, chlorides, nitrates, hydrides, etc., and useful generalizations and summaries of their preparation and properties should be made.

In discussing the manufacture of nitric acid and sulphuric acid it is advisable to emphasize the Physical Chemistry principles involved. In dealing with qualitative analysis reference should be made to questions of relative solubility, preparation of salts, solubility-product, applications of the ionic theory, applications in quantitative analysis, and the sensitivity of tests.

Finally, time must be found both to train the student to use different types of Chemistry books for specific purposes and to find his way round the school, college or public library. He should be taught to read the preface of a book so that its scope and main aims are understood. He should note the date of publication and, if possible, find out something about the author's qualifications. He should know the particular purpose of a book—whether it should be read throughout, serve as a reference book, give background information, supply useful illustrations or diagrams, amplify certain sections of the course, or supply a concise summary of the whole course. Books of all these kinds are required at different times.

The student should be trained to use an index intelligently, and to skim quickly through a book when searching for specific information or ideas. At the same time it is a hall-mark of sound Science teaching to train the pupil to read critically and intensively, but at the same

time to question and check doubtful statements, especially in popular Science books and in periodicals.

Organic Chemistry.—Advanced students are usually taught Organic Chemistry in a manner very different from that used for Inorganic Chemistry. The former requires new methods in laboratory technique, and the use of unusual reagents and more complicated apparatus. The study of the so-called elementary organic substances requires a knowledge of comparatively complicated compounds. The junior syllabus concentrates on Inorganic Chemistry, chiefly of a practical or descriptive nature, with entire omission in many cases of Organic Chemistry. In consequence, unless special precautions are taken, an average student may see little relationship with the work of his earlier years, may be confused by the emphasis on few instead of many elements, and may fail to appreciate the system and generalizations embodied in the use of radicals and the homologous series.

Elementary text-books on Organic Chemistry and many school courses often begin with a description of the methods of detecting the elements present in organic substances and with a treatment of the quantitative aspects of this question. Methods of determining formulae and other connected work are then discussed. The whole of this branch of the subject appears to be treated for convenience rather than on educational grounds. The hydrocarbons are also introduced very early into the advanced courses, and thus not only is little valuable practical work possible, but the preparation and properties of these substances seem to the student to be dissociated from his previous work. Many difficulties can, however, be minimized by using as starting-points everyday substances such as starch, sugar and alcohol (see Figures 2 and 3), or manufacturing processes such as the destructive distillation of wood, fractional distillation of petroleum and coal-tar, fermentation of sugar, and the manufacture of soap. Technical and academic language and difficult equations should be avoided in the early work.

A course in Organic Chemistry might include the features mentioned below:—

1. Instead of the usual notes on the detection of the elements, followed by chapters on the paraffins, the olefines and the acetylenes,

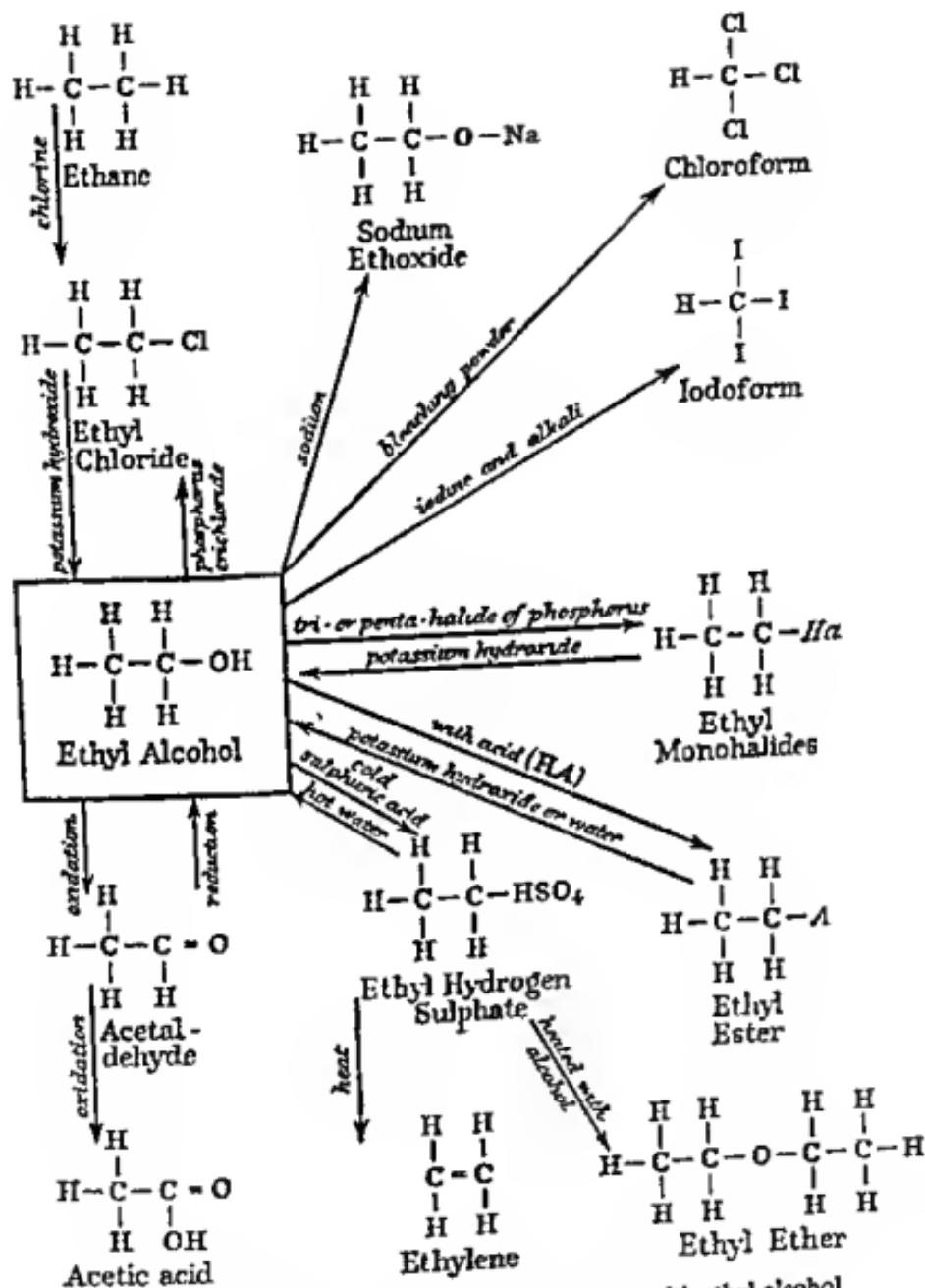


FIGURE 2.—Aliphatic compounds: a chart with ethyl alcohol as the starting-point

the first substances treated in bare outline are starch and sugar. Ethyl alcohol is the first substance dealt with in full detail.

2. Simple experiments showing the typical properties of starches, sugars and alcohols are easy to carry out and give satisfactory results under school conditions.

3. To avoid confusion, simple substances only are dealt with in the first year, and in the second year more complicated substances are contrasted and compared with those discussed in the first year. Thus ethylene, ether and compounds on the right of the chart (see Figure 3) are treated in detail in the second year before the aromatic series is discussed. (For simplicity, tartaric acid, oxalic acid, etc., have been omitted from the chart.)

4. The main issue is made clearer by postponing until the second year the introduction of secondary and tertiary alcohols, isonitriles, secondary amines and a detailed treatment of the unsaturated hydrocarbons. Both aliphatic and aromatic compounds are studied from their structural aspect, by introducing representatives which are typical of the homologous series. Their preparation and properties are related to those of the other members.

5. Each substance is made from its predecessor, and the reverse action is sometimes possible. Each year, the pupils construct a chart to emphasize these points and to stress the system of the course and its inter-relatiooships.

6. The aromatic series is treated in the same manner. Coal-tar is the source of benzene, and this is the parent substance for all the compounds described (see Figure 4).

7. The charts are built up during the final revision. Other charts comparing and contrasting the paraffins, olefines and acetylenes, the aliphatic and aromatic series, ketones and aldehydes, side chain and nucleus compounds, are compiled at suitable stages during the course.

The point of view outlined above stresses human and practical interests, but the alternative aspects of systematic and logical development are not neglected. It should be mentioned that some teachers reverse the emphasis and base their Organic Chemistry courses on logical development.

In teaching Organic Chemistry, constant reference should be made to gradation in physical properties, and similarity in chemical properties, in each homologous series.

At the same time, such anomalies as the unusual properties of the first member of the series must not be overlooked. A typical example is formic acid, which is a hydroxy-aldehyde as well as an acid. Other points which must receive attention are the general properties of each radical, the difference between aromatic and aliphatic compounds but the special uses of nitrogen compounds (e.g., amines and amides) in synthesizing one homologue from another (see Figure 5), and in the wide application of diazonium compounds, should also be which might be introduced, are of the following types: the longer the carbon chain, the higher are the melting-points and the boiling-points (note the interesting alteration which in some series forms an exception) and the weaker is the corresponding acid; a solvent often contains the same groupings as its solute (substances which hydroxyl groups dissolve in water, members of homologous series are usually soluble); isomers with the most compact formulae have the lowest melting-points and boiling-points; a bright colour is often a sign of unsaturation.

During the course the general rule should be that the practical work keeps pace with the theory. It is often advisable for different students to prepare different substances, and at intervals to inspect and make notes on the experiments done by other members of the class.

Notes on a detailed syllabus (see p. 48).—I. The syllabus is primarily intended for students of ages approximately 16-19 who have followed a syllabus basically the same as that given on p. 25.

2. No previous knowledge of Organic Chemistry is assumed. Students who have not covered sufficient junior Inorganic and General Chemistry ought to be brought up to the necessary standard by learning the primary and fundamental parts of these sections.

3. The syllabus is normally a two-year course and the time allowed

week.

4. On educational grounds the treatment should be based essentially on the preparation and properties of important elements and compounds used (a) in the home or in industry, (b) in the laboratory. It should (c) emphasize fundamental processes in chemistry, and (d) illustrate the classification of elements and their compounds, using the electrochemical series of the elements, the periodic classification, or the grouping of chlorides, oxides, hydrides, etc.

5. Allotropy should include treatment of carbon, phosphorus, oxygen, sulphur and tin.

6. A knowledge of the chief chemical (rather than technical) processes for the manufacture of the following non-metallic substances is expected:—

oxygen, hydrogen, ammonia, nitric acid, phosphorus, sulphur dioxide, sulphuric acid, chlorine, hydrochloric acid, gaseous fuels (coal-, water- and producer-gases).

7. A broad outline of the commoner chemical processes involved in the manufacture of the following metals and their compounds is expected (rather than details of technical and metallurgical processes):—

sodium, sodium hydroxide, sodium bicarbonate, sodium carbonate, sodium hypochlorite, potassium chlorate, calcium oxide, bleaching powder, magnesium, zinc, aluminium, iron and steel.

8. Less detailed treatment should be given to headings included in brackets. Alternatively, a further third-year course might include these topics and others such as:—

Fluorine, tin, chromium, manganese and their compounds.

The theory of steam distillation; fractional distillation; eutectics.

Arithmetical problems on solubility products; order of reactions; transport numbers.

Buffer solutions and titration-curves; isomorphism.

Valency in more detail.

Stereo-isomerism; diazonium compounds; more complicated organic compounds, e.g. benzaldehyde, benzophenone, benzoyl chloride, benzoic acid. (Reference to the syllabus of the examining body for whose examination the student is preparing should confirm which individual sections are to be included.)

9. The main features of the periodic classification are best illustrated by more detailed treatment of the alkali metals, the halogens,

the inert gases, and the nitrogen group, in that order. Later the alkaline-earth metals and the carbon group should be included.

10. It is desirable that the metals and their compounds should be dealt with on the following basis:—

- (a) in detail:—sodium, magnesium, calcium, aluminium, zinc, copper, lead, iron (and steel);
- (b) in less detail:—tin, mercury, chromium, manganese and nickel;
- (c) in outline only, as required in the treatment of a particular group of the periodic classification:—silver (except for important compounds in detail, e.g. silver nitrate), barium, cadmium, bismuth, antimony and the non-metal arsenic;
- (d) alloys, to include duralumin, brass, bronze, solder, steel and type-metal;
- (e) to illustrate the general principles of the electrochemical series and the periodic classification.

11. Wherever an element is included in the syllabus it is intended that both the element and its chief compounds should be studied.

12. Finally, due regard must, of course, be given to the particular examination for which the students are being prepared—intermediate B.Sc., advanced or scholarship syllabus of the examining body, etc.

Syllabus of General, Inorganic and Physical Chemistry

1. Hypothesis, theory and law. Methods of Science, scientific attitude. History of Science.

2. Laws of Chemistry—revision and extension of earlier work, with numerical problems.

3. Determination of equivalent weights and atomic weights—Cannizzaro, Dulong and Petit (omit isomorphism and limiting densities).

4. The gas laws—Boyle, Charles, Gay Lussac, Dalton, Graham, Avogadro; specific heats.

5. Atomic theory; history, atomic structure, outline of electronic theory of valency, electrovalency, covalency and co-ordinated valency.

6. Gases. Molecular theory and kinetic theory of gases; diffusion; ideal gases; liquefaction of gases.

7. Molecular weights in solution—depression of freezing-point;

elevation of boiling-point (depressinn of vapour pressure); osmosis; Regnault, Victor Meyer, Dumas and Raoult. Association and dissociation.

8. Volume composition and formulae of steam, nitric oxide, nitrogen dioxide, carbon monoxide, carbon dioxide, sulphur dioxide, hydrogen chloride, ozone and hydrogen peroxide.

9. Solutions—classification. Solids and gases in liquids—salt hydrates; deliquescence and efflorescence. Partition coefficient. Constant-boiling mixtures. Purification of substances—ether extraction, steam distillation, distillation under reduced pressure, crystallization, sublimation and precipitation.

10. Electrolysis. Faraday's laws, specific and equivalent conductivities (not transport numbers or ionic mobilities). Electrolytic dissociation, ionic theory, common ion effect, solubility product. Strong and weak electrolytes, Ostwald's dilution law, van't Hoff's factor, hydrolysis; applications to qualitative group analysis; pH values and indicators (buffer solutions and titration-curves).

11. Thermo-chemistry. Heat of formation, reaction and neutralization. Hess's law. (No experimental details except in a third year.)

12. Chemical equilibrium. Reversible reactions. Thermal dissociation. Law of mass action (without mathematical problems). Influence on equilibrium of temperature, pressure, concentration and catalysts—reference to important industrial processes. Le Chatelier's theorem.

13. Classification of elements—metals and non-metals; electrochemical series, periodic classification; history; modern systems of classification; main features, anomalies, applications; atomic structure and electronic theory. Atomic energy (to be linked also with item 5 above and with the history of Chemistry)—natural radioactivity—structure of the atom—transmutation of atoms—artificial radioactivity, tracers—production of unstable nucleus, nuclear fission—atomic bombs, atomic piles, cyclotrons, atomic power plants—military and non-military applications.

14. Introductory Inorganic course: hydrogen, water, hardness of water, history of discovery of composition of water; hydrogen peroxide; the atmosphere, history of discovery; oxygen, inert gases (helium, argon and neon), ozone; classification of oxides; acids, bases and salts; types of salt; oxidation and reduction.

15. Alkali metals illustrated by sodium and its compounds.
16. Halogens in outline—chlorine, bromine, iodine and their hydrides; chlorates, iodates, chlorites and hypochlorites.
17. Nitrogen—oxides; ammonia and ammonium compounds; nitric and nitrous acids and their salts; the nitrogen cycle.
18. Sulphur—allotropy; hydrogen sulphide; sulphur dioxide, sulphurous and sulphuric acids.
19. Metals—chief ores, outline of methods of extraction; general properties of metals; alloys.
20. Group I. Potassium, copper, (mercury).
21. Group II. Magnesium, calcium, (strontium and barium), zinc, (cadmium and mercury).
22. Group III. Boron, borax, boric acid; aluminium.
23. Group IV. Carbon, carbon monoxide, carbon dioxide, the carbon cycle, carbides; combustion, flame, explosion; silicon, silicates, glass, silicon dioxide and silicon tetrafluoride.
24. Group V. Phosphorus—oxides, chlorides; phosphine, orthophosphoric acid; (arsenic, antimony and bismuth).
25. Group VI. Sodium thiosulphate; (chromium), chromates and dichromates.
26. Group VII. More complex halogen compounds; (fluorine); general methods for preparation of chlorides.
27. Iron and steel; (cobalt, nickel and complex ions); manganates and permanganates.
28. Volumetric analysis.
29. Qualitative analysis:—
 - (a) metallic radicals—lead, mercury, silver, copper, (arsenic), bismuth, antimony, tin, aluminium, iron, chromium, manganese, calcium, strontium, barium, magnesium, sodium, potassium and ammonium.
 - (b) acid radicals—chloride, bromide, iodide, sulphate, sulphite, sulphide, nitrite, nitrate, carbonate, (thiosulphate), orthophosphate, borate, (chromate, acetate, formate, oxalate).

(Note: phosphate separations are not usually required and not more than four inorganic radicals are present in mixtures for qualitative analysis at this stage.)
30. Gravimetric analysis.

Syllabus of Organic Chemistry

31. The carbon atom. Purification of organic compounds. Qualitative analysis of organic compounds, mainly carbon, hydrogen and chlorine, sulphur and nitrogen; quantitative estimation of carbon, hydrogen and nitrogen. Determination of molecular weights.
32. Alcohols—starch and sugars—methyl and ethyl alcohols; empirical, molecular and structural formulae; homologous series; isomerism; primary, secondary and tertiary alcohols.
33. Paraffins—methane and ethane, general methods of preparation and synthesis; fractional distillation of petroleum. Unsaturated hydrocarbons—ethylene and acetylene; unsaturation.
34. Halogen compounds—alkyl halides illustrated by ethyl bromide, chloroform, iodoform and carbon tetrachloride. Substitution and addition.
35. Aldehydes and ketones—illustrated by formaldehyde, acetaldehyde, acetone—polymerization—similarities and differences between aldehydes and ketones; addition compounds.
36. Ethers, esters and acids, illustrated by di-ethyl ether, ethyl acetate, formic and acetic acids; esterification; hydrolysis; dibasic acids—oxalic acid. Oils, fats, glycerol and soap. (Stereo-isomerism.)
37. Amides, imines and cyanides—typical examples, interconversion.
38. Carbohydrates—sugars and starches.
39. Aromatic hydrocarbons—benzene, toluene and xylene—distillation of coal-tar; constitution of benzene; isomerism. Differences between aliphatic and aromatic compounds; side-chain and nucleus.
40. Chlorination, sulphonation, nitration of benzene; preparation and properties of chlorobenzene, sulphonic acids, nitrobenzene, aniline, phenol and benzoic acid.
41. (Benzaldehyde, benzophenone, benzoyl chloride, benzyl alcohol, diazonium compounds.)

Subject-matter for lessons.—It cannot be stressed too often that, whenever possible, topics should be chosen for their local or worldwide and up-to-date interest. Atomic energy is an outstanding example (see item 13 above). It is a subject that should be developed in lectures by teachers and talks by pupils, for the benefit of everybody in the school. Stress should be laid upon the social and moral

principles involved, in addition to the scientific. The historical approach might well be used, and attention drawn to the names of the scientists, in many countries, who have been concerned with the development of the atomic bomb: American, British, Danish, French, German, Italian, etc. (See Appendix A for a brief chart.)

Organization of practical work in the advanced course

The practical work in the advanced course should be carried out chiefly by the students themselves, but occasional demonstrations are advisable. It is necessary to have a sound practical laboratory manual, or, preferably, notes should be typewritten and pasted on cardboard. In this way, numerous reliable and original experiments can be attempted and, furthermore, students can work at their own speed on the experiments they choose. In Inorganic Chemistry, the experiments should be grouped round the important members of the periodic classification, and much unnecessary repetition is avoided by cross-references to the instruction sheet, text-books and library books.

By the end of the course the student should have received training in the use of all standard apparatus and in all types of laboratory technique, including the collection of gases, the use of catalysts, the microscope, and apparatus suitable for the determination of elevation of boiling-point, depression of freezing-point, electrolysis, etc., and in the typical operations of qualitative, volumetric and gravimetric analysis.

When every type of apparatus has been used, time should be saved by carrying out a greater number of experiments on a smaller scale. Thus a whole series of experiments on osmosis can be done in one lesson. For example, two members of the class fit up the usual thistle-funnel and parchment-paper experiment, and the porous pot and semi-permeable membrane experiment. Two more carry out small-scale preparations of semi-permeable membranes. Others carry out simple isotonic tests under the microscope with flower-stalks, etc., in water and salt solutions. The development of 'trees' in sodium silicate solutions and the placing of small, shell-less eggs in water and salt solutions are other variations of this experiment. The advantages of small-scale Chemistry will be shown in Chapter VIII. Many tests in Organic Chemistry can be done on the small scale,

as for example with esters and sugars. The student should certainly carry out one experiment to illustrate each of the more important operations, such as ether extraction, fractional distillation, steam distillation, purification by recrystallization, nitration, sulphonation, acetylation and benzylation, but an excessive length of time should not be spent on organic experiments which involve familiar principles. In later experiments much time can be saved by substituting test-tube work for large-scale experiments.

It is extremely important for the student to know the normal physical state of organic substances, and it is desirable that the school should possess at least a specimen of every substance studied. The principles involved in the preparation, collection and purification of a gas, liquid or solid vary considerably. Students should be given exercises to show that the methods required for preparing and carrying out experiments differ because of the physical state of reactants and resultants. Alkyl halides illustrate this point, for methyl chloride and methyl bromide are gases and methyl iodide is a liquid. Other related substances which require a different technique in their isolation and purification are nitrobenzene, which is a liquid, and dinitrobenzene, which is a solid.

Science courses for non-specialists

It may sometimes happen that an extra class has to be organized, consisting of students who are not specializing in Chemistry. This opens up attractive prospects. Students may be staying for one year only, and while contact is kept with an elementary treatment of the junior courses, there is great scope for experiment. The ideal method is to enlist the full interests of the students in a project, or, if this is not practicable, to start individual schemes in order to cultivate that appreciation of Science which our future citizens should possess. In some cases, suitable experiments may be impossible or few in number; but if a boy who, for example, has passed a first-aid examination wishes to specialize in the science of health, or one interested in plastics wishes to prepare a summary of their modern uses, opportunities for pursuing these interests should be given, and it is usually possible to illustrate features of the topics experimentally. One evening's preparation a week can be devoted to this type of work, and the

laboratory work will have to be fitted in whenever possible. Some students may be unable to suggest a topic, but if their abilities are known, they should be asked to work with a suitable group. Much thought will have to be expended on the student who shows little enthusiasm for Chemistry. A topic must be selected which will bring out the best of which he is capable. Students who definitely dislike academic Chemistry, and who have no examinations in view, might receive some training in the principles of Chemistry by specializing on its definite applications to industry. Others who are handy with tools might be asked to design and make stands for holding apparatus.

Another scheme of work which may be attempted with this non-specialist class is to give descriptive lessons with a few demonstrations. The students have sufficient experimental knowledge at this stage to appreciate to some extent the great generalizations of Science, the influence of Chemistry on industrial history, and topical subjects of local or world interest. Some few students may also be interested in historical Chemistry.

It is unwise to confine consideration to Chemistry only, and a list of suitable subjects for non-specialists might include the following:—

1. Recent discoveries which have improved living conditions of mankind, including treatment of diseases, surgical operations, public health measures.
2. The applications of Chemistry in modern life—e.g. plastics, metallurgy, textiles, drugs, dyes, fuels.
3. Synthetic Chemistry: its development and scope.
4. Scientific life, spirit and methods.
5. The development of Chemistry since 1750.
6. The applications of electricity to industrial Chemistry.
7. Designing visual aids as a means of studying Chemistry: charts, diagrams, photography, graphs, film-strips, models.
8. The study of the sea and its products.
9. Common commodities: e.g. coal, common salt, soap, glass, cement, pottery.
10. Testing superstitions; claims of advertisements.
11. Biochemistry and the human body.
12. Colorimetry: to determine the sensitivity of tests.
13. Important dates: Chemistry and scientific discoveries.

The following is the sort of list that might be used in connexion with subject No. 13:

1688 Distillation of coal: Clayton.
 1709 Coke used in the blast furnace: Darby.
 1714 The mercury thermometer: Fahrenheit.
 1736 The manufacture of sulphuric acid: Ward.
 1785 Chlorine used as a bleaching agent (manufactured in 1733).
 1790 Washing-soda manufactured from common salt: Leblanc.
 1792 Coal-gas used for lighting: Murdoch.
 1814 Photography: Daguerre.
 1826 Synthesis of urea from inorganic substances: Wöhler.
 1847 Chloroform used as an anaesthetic: Simpson.
 1848 The modern safety match.
 1858 Investigation of micro-organisms: Pasteur.
 1860 Ammonia used in refrigeration: Carré.
 1863 The ammonia-soda process: Solvay.
 1865 Celluloid plastic synthesized: Parkes.
 1870 Antiseptics: Lister.
 1895 X-rays: Röntgen.
 1898 Radium discovered: the Curies.
 1906 Synthetic resin: Backeland.
 1910 Ammonia synthesized: Haber.
 1912 Vitamins discovered: Hopkins.
 1928 Penicillin discovered: Fleming.
 (For dates connected with atomic energy, see Appendix A, page 273)

The list could cover other sciences and include such items as the invention or discovery of: steam and internal combustion engines, aeroplanes, spectacles, telegraph, filament lamps, thermionic valves, wireless, television, etc. Students can relate dates of this kind to other important events in art, music, economics, politics and war.

In this 'non-specialized' work, a broad scientific course, or a detailed study of one small section of Chemistry, might prove equally successful. The guiding influence in choice of topics must be the individuality and interests of teacher and students. As in all teaching, enthusiasm is probably more important than depth of knowledge, although both are indispensable factors.

CHAPTER IV

The Teaching of Elementary Chemistry

Preparations on obtaining a first appointment

The position of Chemistry in the General Science scheme is dealt with in Volume VII of this series, and in this chapter reference is made only to Chemistry as an individual subject. The points dealt with, however, will apply in general to the teaching of Chemistry as a separate subject or as a branch of General Science.

The newly-appointed teacher may be in complete control of the subject for the whole of the school, or he may be fortunate enough to be junior to a sympathetic senior science master. In either case, he should obtain copies of the existing school syllabus and text-books and of his time-table. He should acquaint himself with the nature of any external examinations taken and the part Chemistry plays in the General Science course.

The next step should be to read several well-known and successful junior text-books. The books of Holmyard, Sherwood Taylor, Mee, Littler, Sutcliffe, Fowles, Holderness & Lambert in England, and of such writers as Conant, Smith and Brownlee in the U.S.A., ought to be included in the list. In particular the special aspects of Chemistry in relation to Biology should be studied. Not only do these text-books contain up-to-date subject-matter, but they also give useful guidance as to possible teaching methods. University students spend so much of their time in the study of advanced Inorganic, Physical and Organic Chemistry that the more elementary work often becomes indistinct in their memories.

The teacher should note if there are separate junior and senior laboratories, and if these are adequately stocked. He should find out the number of pupils in the practical classes, and if he is to have the help of a laboratory assistant or steward. He should decide if the laboratories are more suitable for demonstrations or for individual work, and should find out if a lecture-room, or a combined lecture-room and laboratory, is available. Questions of this type greatly affect the methods of teaching. The material to be taught is fairly well defined by the external examination, and the organization of the

material should be shown by the syllabus; but the methods of teaching are essentially the teacher's own and can, therefore, be adapted by him to suit all the existing conditions.

It is advisable, in general, to follow the syllabus in use for some time, but the young teacher may wish to modify certain details. He may disagree with the position of some of the lessons in the syllabus, and may, for example, postpone work with the charcoal block and cobalt nitrate, or dry tests with borax beads. On the other hand, he may decide to include a lesson on solubility in the first year and to postpone the lesson on mixtures and compounds.

He may feel that chemical equations ought to be introduced as late as possible, that his own special qualifications and ability, for example in photography or metallurgy, ought to influence the content of the syllabus. Further, there may be good reasons, connected with the position of topics on Chemistry in the General Science syllabus, to modify or amplify the material, and, particularly, to alter the method of approach. Such changes should certainly be made, but it is doubtful if a young teacher should do more until he has had at least a year's experience. It may happen that there is no syllabus available. Such cases occur when an inexperienced teacher is appointed to a new school or when Science is first introduced into a school.

When the teacher clearly understands the connexion between the different years' work, he should compare with his own estimate the amount to be covered each year according to the existing syllabus.

The next step is to write up outlines of each lesson in a small thick note-book, which can easily be slipped in the pocket and is also easy to handle on a demonstration bench. Some teachers, however, prefer a loose-leaf note-book or even a card-index. One side of each page, or card, should be left blank so that notes may then be made, after each lesson, on: improvements in the design of apparatus; failures of experiments; difficulties met by pupils in understanding parts of each lesson, or in obtaining satisfactory results in experiments; useful additional material supplied from other text-books and technical journals; extracts from records of original discoveries; details of local industries and undertakings; photographs and charts; etc. By this means valuable material is collected for use in future years, resulting in steady improvement of teaching technique, in economy of time in reproducing particular facts at the correct stage.

and above all in maintaining a sustained enthusiasm for Chemistry and other branches of Science—of necessity the most important quality of a Chemistry teacher. As soon as possible, the whole of the junior course should be written out in full. In every lesson, the teacher should incorporate the methods which appeal to him. He may decide to adopt some of the schemes alluded to in this book, such as the application to local conditions, to biochemistry, to the historical method or to a modified Dalton plan. In the Dalton plan, carefully designed assignments or problem-cards enable individuals to cover a wide range of experiments and topics at their own speed. The instructions, best prepared by the teacher himself, are mounted on cardboard, varnished and numbered. They should give full details for practical work as well as further help in the form of questions and of references to books for the pupils' reading.

The teacher must certainly decide if he is to include the maximum number of individual experiments for the pupils, or if he will demonstrate rather more than the accepted number. Such decisions will influence the type of apparatus and the content of each lesson, which should occupy a double period during the first-year course. The exceptions to the latter rule occur when revision or tests take up part of a lesson.

In addition, the teacher must bear in mind that there are other sources of information which the pupil should use. He must pay particular attention to the need for a text-book to harmonize with the school work. Early lessons should be supplemented by direct reference to the text-book, which usually supplies diagrams, sketches and additional information. After completing the first year's course, definite reading and summarizing of special sections of the text-book should be carried out by the pupil.

Different expert teachers advise different methods of approach to the use of a class text-book. Some indeed advise against the use of any text-book in the first year. The author feels, however, that even a good school library is insufficient to supplement the pupil's own notes. Particularly is this true for brighter pupils, who prefer their own text-books so that they may study on their own, read more widely, and have a reference book for checking their own observations.

It is not easy to find suitable text-books which deal with Chemistry at its early stages in straightforward simple English, or to find

readers or supplementary books in Science which are specially written for the beginner. The use of a ready-made skeleton book for the first year, which supplies clear instructions to carry out practical work, provides help in training the pupil to write notes, and gives supplementary notes, is one solution. In the U.S.A. more comprehensive laboratory note-books, manuals and work-books have been produced to satisfy this demand.

The first two lessons in elementary Chemistry

A preliminary talk should arouse interest and should give some idea of the work to be done. It should be pointed out that, while Chemistry is essentially studied for its own sake, there are also other reasons for mastering its subject-matter and its methods (Chapter II). Further, as an essential branch of the General Science course, it helps in the understanding of sections of Biology, Physics, Geology and Geography. A notice-board should be provided for cuttings from current newspapers and magazines. Chemistry as a hobby should be encouraged, and boys should be invited to bring from home specimens and spare materials for experiments. The first part of the lesson should deal with such subjects as laboratory arrangement, laboratory rules and the entering up of notes. The system of marking (see Chapter X) should be explained, and, if possible, the day for handing in homework should be settled. In the second part of the lesson, the teacher should sketch the broad outlines of Chemistry up to the time of Robert Boyle. Pupils thus gain an idea of the antiquity and scope of the subject. When the note-books are handed in it is possible to find out if the pupils have understood the work. It is advisable for the teacher to keep a record of the mistakes made, and also to note his own impressions of the lesson.

Before beginning the second lesson, the teacher should make sure that the apparatus is available on shelves or that pupils' lockers are completely stocked, and that the other necessary material is put out on the benches. If no printed matter is used, instructions should be written on the blackboard before the pupils enter the laboratory. Reference should be made whenever possible to text-books, as these may contain, for example, details of further experiments and photographs of historical apparatus. For illustrative purposes it is assumed that the second lesson is on the Bunsen burner or gas-stove. Before

dealing with laboratory sources of heat, however, the errors of the preceding lesson should be discussed. This satisfactorily accomplished, the aims of the immediate experiments must be stressed, and the pupil must have no doubt as to the instructions to be carried out. If a text-book or typewritten copy of instructions is not in use, the pupil should make a copy of these from the blackboard into a small note-book. Not more than fifteen minutes should be spent on this part of the lesson. When the experiments begin, the teacher should walk round the laboratory and, as far as possible, discuss important points with each pupil. He should ask questions and correct anyone who is not handling the apparatus properly. One pupil may have to be prevented from stopping up the gas inlet and another from burning the charcoal block. On the other hand, if a boy obtains an exceptionally good charred circle with a piece of glazed paper held in the flame it should be kept for class reference. Pupils may occasionally work in pairs, and should be allowed to discuss minor matters. They should certainly be given more freedom than in a classroom, but the teacher should be able to get instant attention, e.g. by ringing a small table-bell, if he finds a common error being made or if he wishes to give further instructions.

When the pupils have completed all their experiments, cleaned the apparatus and tidied up the benches, further class discussion is necessary. The experiments should usually be finished in from thirty-five to forty-five minutes, leaving twenty to thirty minutes for reviewing in detail the whole of the work. In large laboratories, pupils working on the back benches might be brought nearer to the teacher's bench for this discussion, or if a school is sufficiently fortunate to possess a special lecture-demonstration room, pupils should be moved there. The aims of each part of the lesson should be stated, and one pupil should be asked to give an account of the first experiment. The others should be asked to criticize any statement which they consider incorrect, but the cleverest pupils of the class must not be allowed to do all the work. Thus an exact and precise verbal description of the first experiment should be built up, and the pupils should make notes at this stage. The whole of the instructions should be worked through in this way, and as many of the class as possible should contribute information. The most difficult part of the lesson is the formulating of inferences from observations, and this is impos-

sible unless the instructions are accurately worded and the questions well thought out and to the point. Having questioned pupils during the experiments, the teacher will now be aware of the difficulties encountered. He should also have found time to scan a few of the note-books and should be able in consequence to pass quickly over the easy parts of the lesson. In other sections, it may be necessary to supply new data or to make certain definitions more precise. New or difficult words should be written on the blackboard. Emphasis should be laid on the sectional method of drawing (Chapter XI), and pupils should be reminded of the way in which the material is later to be written up. If the teacher feels that some experiments should be demonstrated, a good method is to use large apparatus. A large Bunsen burner can be erected as follows:—Gas is passed through a piece of glass tubing which is bent at right angles and drawn out at one end. This end is fitted into a cork clamped underneath a long piece of wide metal tubing (or glass tubing with a thin sheet of copper tied round the top end). The gas can be lit and, by altering the position of the tube, it is possible to demonstrate 'burning-back', and the different cones of the flame, in a most effective manner (see Figure 6).

There are numerous side-lines in this particular lesson on a Bunsen burner. A gas-stove or blue-flame oil-stove is based on the same principle as the burner, and the lesson should centre round one of these when teaching girls. Boys may feel that they can improvise Bunsen burners from scrap material, and they should be invited to bring their models the following week. Reference might be made to coal-gas, explosions in mines, soot, heat-sensitive paper (blotting paper soaked in a solution of cobalt chloride and a little ammonium chloride), the first sources of heat, Priestley's lens, Davy's safety lamp, the Primus stove and the blow-lamp. Intelligent future citizens should be acquainted with the main outlines of such topics, and this incidental treatment at an early stage is sound educational practice.

If three rather than two lessons can be given to the study of such a

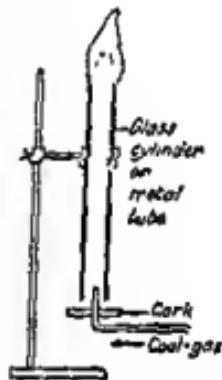


FIGURE 6.—
Diagram of an apparatus to show the principle of the Bunsen burner

topic, the different sections may be developed still further by stressing the applications referred to in *General Science* lessons (including Homecraft); the coal-gas industry; the consumption and cost of coal-gas or alternative sources of heat used when coal-gas is not available. The danger of carbon monoxide poisoning should certainly be explained in connexion with incomplete combustion of fuel in stoves and the exhaust-gases of motor-cars.

Pupils should be referred to the notice-board and to helpful books in the school library. Finally, the subject for the following week—to compare the solubility of common substances in cold and hot water—should be mentioned. Pupils should be asked to bring samples of such substances as alum, plaster of Paris, sulphur, charcoal, nitre, common salt and sugar for their individual experiments.

It is advisable to give the pupils information about next week's topic and, for example, to set them the problem of suggesting how to compare the solubility of these substances by simple means, using no balance but only very simple apparatus in the laboratory. They might be given preliminary help by asking them how it is possible to measure small amounts of powdered solid substances and how they could find the volume of a test-tube.

It is a sound plan to supply brighter pupils with copies of the term's syllabus so that they are aware of problems to be tackled, and so that they may read widely round the subjects.

General methods in later lessons

The majority of the double-period lessons (eighty to ninety minutes) should be divided into three connected parts as described in Lesson 2. In the first part of the lesson, a series of quick revision questions helps the pupil to see the connexion between the material to be introduced and the earlier work. A well-arranged syllabus ensures continuity, but time is well spent in emphasizing such relationships. In the second part of the lesson, pupils should carry out the experiments and record their observations and conclusions. During this time the teacher should be busy helping individuals. The class discussion at the end of the lesson should summarize the work and leave the pupil with clear and definite impressions of all that has been done. In the final concluding minutes, the following week's work should be introduced. In some of the later lessons, the mode of pro-

cedure described above may occasionally be altered. The pupil should be set a problem, or be given certain instructions, and he should make a written account of his experiment as it proceeds. On other occasions, wooden or cardboard models, or the building-up of a chart, or the reading of an extract from the writings of an original discoverer, or an eye-witness account of a particular event, or a striking experiment, may be the means of completing and reinforcing a lesson.

The general approach to each lesson should be through problem-situations linked with the pupils' interests. It is unwise and indeed impossible to have a uniform method, but the essential ideas should be approached through inductive teaching, i.e. from the particular to the general. The experimental results should lead to the framing of generalizations, so that facts are obtained and then built up into generalizations, concepts or principles. Later, these principles or laws should be applied deductively to solving problems.

Thus, the essential order of a lesson is of the following type:—

1. The problem arises and is set out in clear and simple terms.
2. Discussion centres around its solution, i.e. hypotheses are suggested by the pupils, and evidence given for each, as a means of solving the problem.
3. Experiments are suggested so that when they are carried out they may test the hypothesis.
4. The results are obtained, records are made, and conclusions are drawn from this evidence with special reference to the problem.
5. Further experiments are made, text-books and reference books are consulted, and other relevant information is collected and classified.
6. Complete records of the experimental results and the conclusions drawn are made in the pupil's note-book.

Some lessons in the first year's work will include demonstrations by the teacher. Typical examples are: the burning of coal-gas bubbles (Figure 7 (a)), the passage of steam over heated iron, the synthesis of water, and the action of sodium and potassium on water. Some teachers allow pupils to drop small pieces of sodium and potassium on water and collect the hydrogen evolved; but the author advises that these experiments should be carried out only as demonstrations under the control of the teacher (see Figure 7 (b)), yet at the same

time, as a problem to be solved by the pupils. The brighter pupil is very critical, and will not be satisfied unless the experiment gives good results. Accordingly, the young teacher should always first rehearse the demonstration in private. In this way any minor irregularity which occurs can be corrected, and later, when in front of the class, the teacher will feel confident of a successful demonstration.

The aim of the teacher should be to avoid confusion in the pupils' minds. He will gradually acquire facility in anticipating the difficulties encountered by pupils, and will find out, by experience, how to obviate or explain these points. A discussion of some of the com-

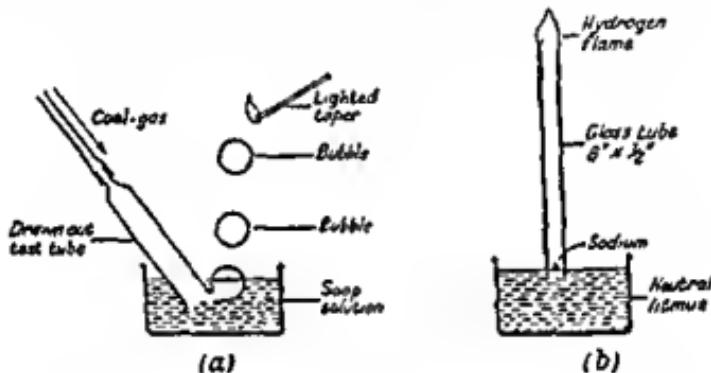


FIGURE 7.—Demonstration experiments:

(a) Burning bubbles of coal-gas
 (b) Burning hydrogen from the action of sodium on water

plex reactions occurring in the early experiments serves no useful purpose, however, and must be postponed for later years. On the other hand, a few of the reactions provide much useful material for study.

Generalizations should be aimed at whenever possible, and stress should be laid on statements such as the following: silver nitrate solution is used for testing all soluble chlorides and not only hydrochloric acid; nitric acid is prepared by the action of concentrated sulphuric acid on any nitrate and not on the sodium salt only; all salts of sodium, potassium and ammonium, and all nitrates, are soluble in water; only the gases hydrogen and ammonia are collected by the upward displacement of air (Figure 8).

In contrast, such varied results and unusual reactions as the

following should all receive emphasis:—the different effect of heat on the several classes of nitrates; the different agents needed for drying different gases; the spontaneous inflammability of phosphine; the high solubility of ammonia and hydrogen chloride; the fact that the normal oxides, e.g. cupric oxide, rarely evolve oxygen on heating; and the varied actions of acids on metals.

Each series of reactions should receive appropriate treatment, e.g. the effect of heat on nitrates should be summarized and linked with the preparation of gases, e.g. nitrogen oxide and nitrous oxide, or with the electromotive force series showing the relative chemical activity of metals. On the other hand, advanced pupils might well

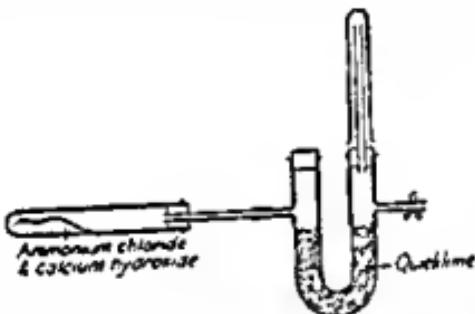


FIGURE 8.—The preparation of ammonia gas (small-scale)

develop the principles of drying gases by building up a summary such as the following:—

Acidic gases: dry with acidic drying agents, e.g. concentrated sulphuric acid, or neutral agents.

Basic gases: dry with basic drying agents, e.g. quicklime or caustic soda.

Neutral gases: dry with any type of drying agent, e.g. phosphorus pentoxide, or solid caustic potash, or calcium chloride.

The end of the first term

When the first term is completed, it is possible to review the progress of each class and to decide if sufficient ground has been adequately covered. The teacher will, by this time, have a fair estimate of the capabilities of each class and each individual and will have discovered which are the enthusiastic pupils with a thirst for chemical knowledge. He will also have estimated to what extent the school text-books

fit in with the syllabus. It is always worth while to compare the contents of each lesson with those in elementary text-books. The methods adopted in factual lessons, based on experiments, depend entirely on the initiative of the teacher. Arousing interest, the arrangement of subject-matter and its presentation, questioning and answering, the framing of a hypothesis or reaching a conclusion, are quite as important as the facts. The facts themselves should be presented as attractively as possible, and junior work should be helped by constant reference to occurrences in everyday life.

The school library should contain books on Science in everyday life, Historical Science, General Science, etc. (see Appendix B). A nearby Public Library may prove useful in providing popular Science books. It may also have helpful periodicals (see Appendix B.6), but every school or Science teacher should try to subscribe to such journals as *The School Science Review*, *School Science and Mathematics* and *The Science Teacher*.

Another feature of the teaching of Chemistry is the desirable but difficult aim of attempting to correlate the subject with Physics, Mathematics, Biology, Domestic Science and Health Education, and to some extent with Geography and History. References should be made to each syllabus, and co-operation with the heads of each department should be of mutual advantage. Thus, the gas laws require a knowledge of ratio, proportion and logarithms, which are usually taught in Mathematics.

Pupils are often handicapped throughout the Chemistry course by their difficulties in carrying out particular arithmetical operations involving percentages, decimal calculations and the unitary method. Indeed it is advisable in the early stages to select problems in Chemistry which avoid difficult calculations, so that stress is laid on the chemical principles rather than on proficiency in Mathematics. It is a great advantage to use a slide-rule at this stage; there is no need to teach the theory of logarithms: the processes for multiplication and division can be taught as mechanical operations in a few minutes. It is also strongly recommended that the arithmetical operations should be carried out by the same methods in both Science and Arithmetic lessons. Consultation between Physics and Chemistry teachers is necessary in dealing with electrolysis, the gas laws and, later, with the molecular theory of structure, surface ten-

A VOGADRO'S LAW:—

Equal volumes of gases contain the same number of molecules

B OYLE'S LAW:—

The volume of a gas varies inversely as the pressure

$$v \propto \frac{1}{P} \quad \text{or} \quad \frac{v_1}{v_2} = \frac{P_2}{P_1}$$

C HARLES'S LAW:—

The volume of a gas varies directly as the absolute temperature

$$v \propto T \quad \text{or} \quad \frac{v_1}{v_2} = \frac{T_1}{T_2}$$

Combined:

$$PV = RT \quad \text{or} \quad \frac{P_1 V_1}{P_2 V_2} = \frac{T_1}{T_2}$$

of the

Gas

Laws

GAY LUSSAC'S LAW:—

Gases combine in whole-number proportions

FIGURE 9.—The 'ABC' of the Gas Laws—a chart

sion, boiling-points and melting-points; with the Biology teacher in dealing with the composition of the air, respiration, solution, fertilizers and, later, with topics such as diffusion and osmosis. Geography teachers may find difficulty in explaining the meaning of solution, melting, combination, metal, ore, etc., and both geographer and chemist should discuss mutual teaching problems to avoid confusion in the mind of the pupil. It is most helpful if specialist teachers can agree to use similar terminology, although a different treatment of the same subject is not necessary. Such an arrangement is particularly valuable in the teaching of Domestic Science, Homecraft, and Health Education, when dealing with ventilation, gas-stoves, cleanliness, baking and washing, preservation of food, bacteria, etc.

Many other examples which stress the importance of correlation and the necessity for co-ordination of school subjects will occur to the reader.

It must not be forgotten that an inspiring text-book often provides an alternative viewpoint which may appeal to some of the pupils. In any case, it must on occasions be used as a reference book. In consequence, the earlier laboratory work should be connected with the pupils' text-book by giving definite references to pages dealing with

the subject. Later, the pupils should be able to find the references for themselves. For homework, a preliminary reading of a prescribed part of the text-book may be set, or an especially lengthy but useful portion may be summarized. Sometimes questions may be set requiring intelligent revision or application of past work. At other times, pupils may be asked to design apparatus suitable for a particular experiment or to write an essay on a general topic. Suitable subjects for essays include:—air and its uses to man; hard and soft waters; the history of the chemistry of air; metals and their uses; sewerage and drainage; building a new house; how to keep fit; and sources of pure food. The contents of the essays should not be confined to Chemistry but should include references to other branches of Science.

Problems to be considered as the teacher becomes more experienced

After several terms' experience, the young teacher may decide to modify or extend the syllabus. He may find that certain sections of the old syllabus are unsuitable. Even if he retains most of the material, he will probably wish to introduce new apparatus and methods in order to stress points which he considers important. For example, he may feel that the atomic theory and chemical calculations have been included too early in the course; or that the chemical aspects of electrolysis of solutions ought to be introduced earlier to coincide with the teaching of electricity; or that the introductory lessons might include training in the use of apparatus employed in the chief operations of Chemistry, e.g. in solution, filtration, sublimation, distillation and fusion, using simple substances such as sulphur, ammonium chloride, sea-water, nitre, sand, salt, coal, etc. More important, he may feel it advisable to rearrange the whole syllabus on entirely different principles. He may decide to group much of the junior work around general topics—e.g. air, water and earth—or to base much of the work on metals or the electromotive force series, or to introduce the ionic theory at an earlier stage in the syllabus. His decisions must be largely influenced by the teaching of General Science at lower levels. If so, he should rearrange the order of the syllabus to fit in with his views. Now that experience has been gained, he can compare his ideal syllabus with those given on pp. 25 and 48. In rearranging a scheme of work, the following points should be

considered: the varied abilities of the pupils, the limitations of the laboratory and equipment, the external examinations in view and the time allowance. The teacher must adapt his scheme to the particular conditions. He will also find it more satisfactory to simplify the syllabus for a weaker, parallel class. While the main outlines should not be changed, minor points may be omitted, some topics may be dealt with more slowly and from different angles, a minimum number of facts should be supplied, and general principles should be learnt. It may be tempting for an enthusiast to deviate from the main issues if interesting side-reactions occur, but, on the whole, junior pupils cannot appreciate references to such facts as, for example, that pure zinc is not attacked by pure sulphuric acid, or that copper forms cuprammonium salts, or that when magnesium burns in air it forms its nitride in addition to its oxide. Questions such as these should be reserved for individual or group-work with brighter pupils.

In the third and fourth years' work, the extra time allowance and the nature of the work necessitate a slight rearrangement of the scheme of teaching. The double lesson is given to practical work, and notes on the experiments may occasionally be written up by the pupils in the laboratory, so that homework can be devoted to some other aspect of Chemistry. Practice must be given in answering questions on past work, in building up revision charts, in solving practical problems, in summarizing sections of the text-book and also in systematic reading. In general, however, rather more than half of the time allotted to homework might be spent in amplifying the skeleton notes taken in the laboratory, and in answering questions. The pupil thus compiles an orderly account of the year's work. Each pupil should have a small note-book for rough work and another for combined theoretical and practical work. Single lessons in later years are rarely spent in practical work. This gives more time for descriptive work, revision, treatment of topical subjects, talks by the pupils, fuller discussion of the week's practical work, answering written questions and working out numerical problems. The theoretical lessons provide excellent opportunities for consolidating the portions of the syllabus which have been covered, and for widening the pupils' outlook. The revision work in the last year requires that some lessons must be given to covering a large number of facts. Theoretical Chemistry should now be co-ordinated with the experimental work,

the general rule being to base theory on practice. In later years the determination of equivalent weights, and experiments on the composition of gases and the law of constant composition, introduce many aspects of theory. The construction of equations and solution of numerical problems are other aspects which cannot be omitted.

The development of the individual pupil

Varied teaching aims and methods are necessary to allow for the wide difference in ability and interest of the pupils in each class. Both written and verbal accounts must be given so that the pupil who fails to benefit from one method has the opportunity of developing clear conceptions from the other. Sometimes individuals should carry out different experiments on the same topic, and they should be allowed to describe the parts of the experiment which most appeal to them. A topic such as the 'fixation' of nitrogen provides an illustration of how all the pupils may be employed so that each takes an active part in the lesson. A boy interested in Biology examines the nitrogen-fixing bacteria under the microscope; one interested in gardening finds out facts about natural and artificial manures; a pupil interested in business notes the increase in the sale of 'fixed' nitrogen during recent years; another, with militaristic tendencies, sees the importance of nitric acid for explosives; the organizer charts the nitrogen cycle (see Figure 10); the girl interested in dietetics and food values studies the question of the nitrogen content of food; the mathematician plots graphs of the annual production figures for natural and synthetic fertilizers from year to year; the geographer finds out the sources and special uses of nitrates, phosphates and potassium fertilizers; and the librarian looks up information on any of these topics.

Such figures as the following may be the means of stimulating a discussion on the reasons for, and the effects of, changes in world production:—

Source	World production of nitrogen compounds		
	1900	1912	1934
Air (Nitric acid, ammonia, etc.)	0	7.3	74.5%
Coal	33.4	37.3	18.6%
Chile saltpetre	66.6	55.4	6.9%

Group work may be centred on subjects such as electricity in the

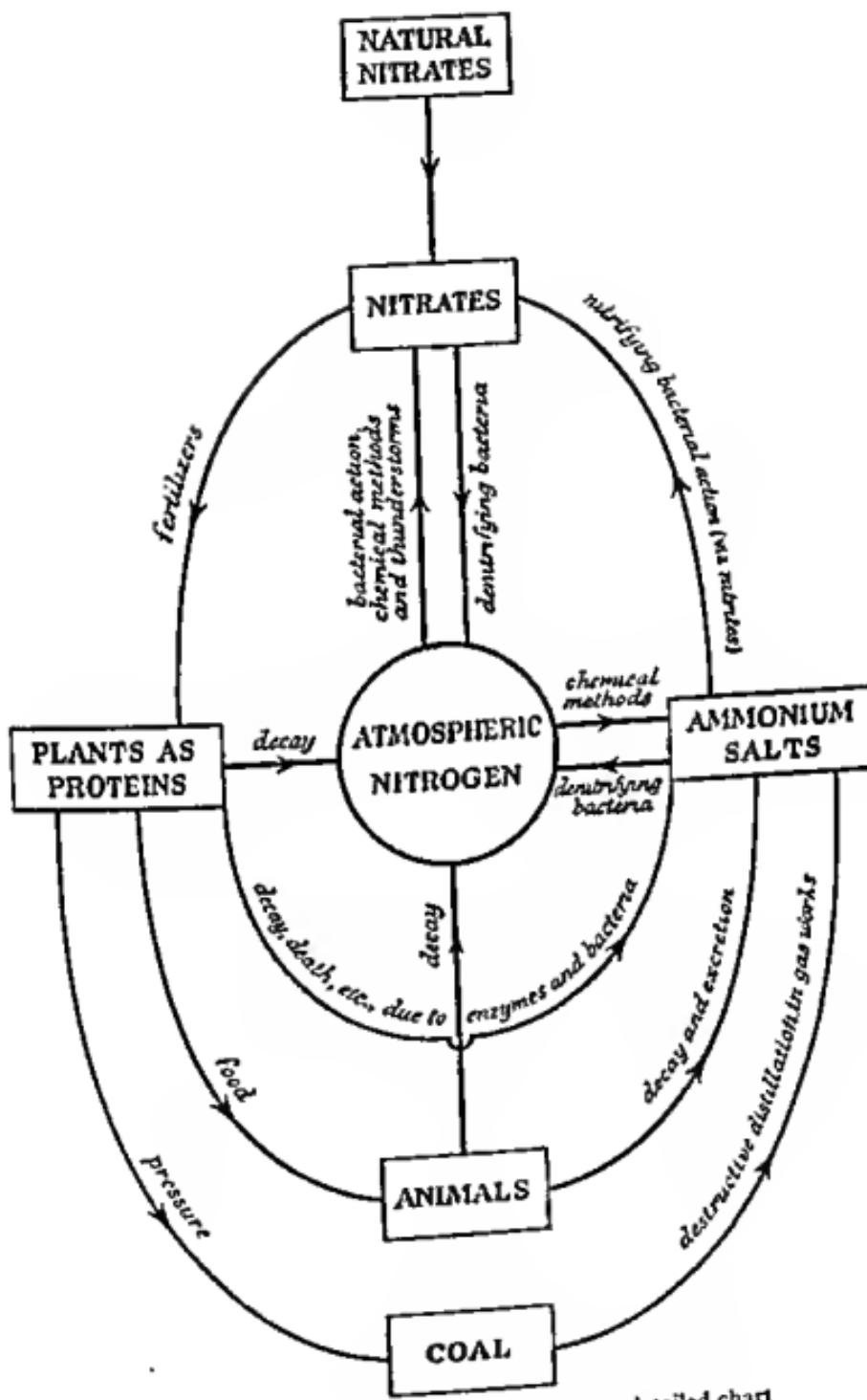


FIGURE 10.—The 'Nitrogen Cycle': a detailed chart

service of Chemistry; calcium carbonate, its different forms and uses; local industries; the mineral acids and common salt. Individual pupils should be encouraged to prepare lectures and wall-charts. A box should always be available in the laboratory so that pupils may ask questions by writing them out and placing the papers at will in the box. Lists of questions relevant to the matter being dealt with ought to be typed out and pasted on cards so that brighter pupils may write out their answers at times when they are unoccupied. In many schools the lessons tend to settle down to the same regular routine. Not only should pupils be trained not to rely on one textbook, but they should also be given definite projects so that they consult Physics and Biology books, library books, catalogues and encyclopaedias. Further, if they suggest, for example, that, since mercuric oxide evolves oxygen on heating, lead and copper oxides will do likewise, they should carry out experiments in the laboratory, even if the results are negative. Such aspects may be introduced by questions in classwork (either from teacher to pupil or pupil to teacher), by reading in the school library, by demonstrations to the class, or by informal talks with parents and friends.

It is clear that a teacher must read widely around the topics dealt with if he is to satisfy the curiosity of the individual pupil. In addition the teacher should frequently introduce valuable information on Science in other lessons. It is assumed that special lessons on health and hygiene will also be given. Girls often inquire about the softening of water, the comparative hardness of local water supplies, the working of gas-stoves, the cleaning of metal-work, the removal of stains, the pasteurization of milk, and similar subjects. Boys may ask for details of the manufacture of iron, the properties of duralumin, the working of the oxy-acetylene blowpipe, preservation by cold storage, etc.

Many of the benefits gained from efficient Chemistry-teaching cannot readily be assessed. This is particularly true of such aspects as the pupil's attitude towards Science and life, his laboratory technique and the scope of his general reading. An onlooker cannot determine the value of the replies given in classwork, or the merit of the questions, unless he is well acquainted with many details. He must consider, among other criteria, the exact position of the special lesson in the carefully planned syllabus, the reasons for bias in a

certain direction, the standard of intelligence of the class, the relationship between the practical and theoretical work, whether the subject-matter is revision or new work, and whether the methods are likely to have a lasting impression on the pupil's mind. Some pupils are inactive during oral work, but are particularly good in written work; consequently they obtain good marks in examinations. Other pupils are the reverse: their oral work is encouraging and inspiring, but they find difficulty in expressing themselves on paper. Most classes, however, are composed of varied types of pupils, and a young teacher must not judge the ability of the whole class from the answers of a few individuals. With experience, the teacher will learn to balance the logical answers of the brilliant pupil against the erroneous replies of the impulsive and erratic one.

The interests of pupils.—The possibility of building up a syllabus with a bias towards the pupils' own interests might be considered. The writer collected the following views from English boys aged 11-16. The number of replies, about 1,000, is comparatively small, but they give some idea of the sort of research that might be attempted. The questions and answers were:

1. Name any subject of particular or general interest you would like to study.

The subjects chosen were in this order of popularity: aeroplanes, motor-cars, engineering and engines, electricity, Chemistry, Nature, games.

2. Would you like to learn Nature Study and Biology?
Forty-eight per cent.—No. Fifty-two per cent.—Yes.

3. Are you more interested in animals or plants?

Animals—ninety-two per cent. Plants—eight per cent.

4. Are you interested in hygiene and the study of the body?
Seventy-nine per cent.—Yes. Twenty-one per cent.—No.

5. What is your hobby?

Forty-seven were mentioned, the most popular being, in order: stamp-collecting, reading, Chemistry, cycling, Meccano, games.

6. What works or factories would you like best to visit?

The most popular in order were: chocolate and cocoa, biscuit, motor, Meccano, aeroplane, ammunition, soap, railway works.

The external factors influencing the above replies were: the

environment of the school, the advertisements of certain firms, the material of recent lessons, and the age of the boys. The replies are instructive and illuminating. They show the wide interests of schoolboys and the slight extent to which school subjects are based on these interests. Much research would have to be carried out in other boys' and girls' schools before pupils' interests could be definitely made the centre of uniform syllabuses. Each teacher, however, can easily find out the interests of the pupils in his own school, and these interests should be considered whenever a course is being planned, or an illustration is required for a specific principle.

From the above replies it is seen that these boys preferred a reference to an animal rather than a plant, to an aeroplane or motor-car rather than to a bridge or building. In such cases a Science lesson should be arranged so that references are made to the subjects holding the greatest interest for the boys.

Houslop and Weeks² state that Chemistry and Gymnastics are the two most popular subjects with English boys, and that they are liked by pupils of widely differing abilities. In contrast Physics and Latin are generally disliked. The advantage of an initial interest does not mean that the pupil will be amused or entertained by Chemistry, but that he is willing to work voluntarily in learning it, and that it is relatively easy to convince him that Chemistry is a subject meriting his attention.

Further, analysis of the contents of magazines and books read by boys and girls in both the U.S.A. and Great Britain shows that there is a definite demand for clear factual description of mechanical inventions and of scientific phenomena connected with Chemistry. The need is greater with boys than girls, but both sexes appear to require books which supply up-to-date and precise information rather than semi-popular and often inaccurate accounts.

The progress of a lesson

1. Each pupil should be allocated to a particular bench at the first lesson. In future lessons he should always go at once to the same bench, so that a quick start can be made.
2. A certain amount of subject-matter must be covered in each lesson. Too much should not be attempted, as allowance must be

² *School Science Review*, No. 109.

made for any legitimate deviation which occurs. The chief facts and principles should be summarized, and these should form the basis of the lesson. Much more material than the mere outline must, however, be prepared by the teacher.

3. Chemicals, reagent bottles and apparatus required should be put out beforehand on each bench.

4. Instructions should either be already written out on the blackboard, or printed instructions or text-books should be available.

Further useful advice to a teacher is as follows:—

5. Keep an eye on the clock. In practical work avoid (by providing additional problems) the best pupils' finishing the experiments in a quarter of the time, and (by giving judicious help) the slower boys' leaving theirs uncompleted. The class should be told of the time remaining at various parts of the lesson and of the rate of progress of the average pupil.

6. In class discussions and demonstrations make sure that all can see the apparatus and the blackboard. See that those who are hard of hearing, or have bad eyesight, are at the front of the class and helped by the use of blackboard and discussion respectively.

7. Be sure that the lesson under review connects the previous week's fundamentals with those which are to follow.

8. When it is apparent that a certain point is not clear, try a different approach. Be prepared to spend a few minutes on earlier work so that the question is thoroughly understood. Try to determine if the partial failure of any lesson is due to the pupil or to yourself.

9. Try to keep all the class busy. Be on the watch for signs of boredom and lethargy, and give ample opportunity for pupils to answer questions.

10. Do not give a class of lively youngsters the chance they will welcome by an invitation to 'come and have a look at this experiment'. The resultant stampede of thirty-five boys to view, for example, a small crystal of alum is of no educational value. It is better to pass a small exhibit round the class or to line up the pupils in single file.

11. Do not ask a general question of the type 'describe last week's experiment' so that it is not clear what answer you require. Be direct and definite when questioning.

12. Avoid monotony of subject-matter and of delivery.

13. Ask a friend to point out any peculiarity of pronunciation, delivery, or other mannerism, or the persistent repetition of a common phrase.

14. It is more difficult to teach in a laboratory than in a classroom. Stools are uncomfortable and may be noisy unless pieces of rubber are screwed under the feet of their legs. It is often difficult for the pupils to see the blackboard. There are many temptations to handle apparatus and reagent bottles during the theoretical part of the lesson. The permanent remedy is to have adjacent lecture-rooms, or a combined laboratory and lecture-room. The temporary remedy is to arrange the pupils in as systematic an order as possible, to make sure that the blackboard and demonstrations can be clearly seen by all, and finally (and of the utmost importance) to get the pupils thoroughly interested in their work.

Tests in Chemistry

Constant revision is necessary in the teaching of Chemistry, and this is often introduced in an incidental manner. The majority of the lessons are prefaced by connecting new topics with old ones. Systematic oral questioning will give the class further opportunities for revision. In addition, occasional written tests ensure that each pupil has acquired a definite understanding of past work. A teacher should determine at what rate the class has progressed. Well-planned tests will enable him to find out the cause of many difficulties. Certain words may still be retarding the development of juniors; the meaning of definitions may not be clear; facts may be known, but pupils may be unable to reason from them. The tests should often cover the work of a period of three to four weeks, when the study of a set subject, such as the atmosphere, has been completed. Tests should also be given on individual lessons and on the study of special sections of the text-book. Questions covering a wide field may be set for homework or classwork when a complete answer is required. Here it is possible to stress the importance of the facts, the arrangement of the material and the style of the answer.

Written tests in class should more often be of a different type. Twenty to thirty short questions should be asked, and the pupils should write down their brief replies immediately. Intelligent and industrious pupils are usually ready with quick and accurate answers,

so that on the whole the results of the test indicate the relative progress of each individual. A reasonable number of factual questions should be asked on the subject-matter which has been considered. Short and definite answers should be expected. Thus:—

1. Give the chemical names (not formulae) of the following: spirits of salt and washing soda.
2. Explain the meaning of the following terms and give one example of each: deliquescence and thermal dissociation.
3. Give one chemical test to find out if a substance is red lead or mercuric oxide; carbon monoxide or nitric oxide.
4. What is the approximate specific heat of a metal of which the atomic weight is 112?
5. Give equations for and name the products of the reactions: the action of heat on (a) a mixture of iron and sulphur; (b) sodium bicarbonate.

In tests of this type, the pupil must clearly understand from the nature of the question what answer he is expected to give. Such precision is to be recommended, as pupils are sometimes misled by the vagueness of examination questions. For example, if the question is 'how is oxygen made?' the pupil will not know if he is to supply details of the commoner sources or of several substances used in a laboratory preparation, whether he has to include reference to the manufacture of oxygen, or if he has to describe the laboratory preparation of the gas.

In some questions, it is advisable to ask for a definite number of illustrations. For example:—

1. Give four examples of oxidizing agents.
2. Give the names of two other substances which are formed, in addition to sulphur dioxide, when concentrated sulphuric acid is warmed with copper.
3. Has sulphur dioxide approximately the same density, a smaller density, or a larger density than air?
4. Name two gases which have a smaller density than air.

Revising from an experiment.—Useful revision questions can be included following on experiments. Thus, pupils might be asked to reduce litharge by hydrogen. Questions of the following type might be included in such a test:—

1. What other oxides can be reduced in this way?
2. What oxides cannot be reduced in this way?
3. Could you collect the water evolved in the reduction?
4. Give a list of four substances which absorb water. To what class do they belong?
5. How is the composition of water determined by the findings of this experiment?
6. Could you determine the equivalent of lead by this experiment?
7. Give reasons for any inaccuracy in your results.
8. What weight of lead forms if (a) 10 gm., (b) 10 tons of litharge are completely reduced?
9. Which substance is reduced and which is oxidized in this reaction, and why?

In the junior stages direct questions of varied type should be substituted. These tests, and others, should be devised or collected by the teacher, classified according to the order of the lessons and written up in a note-book. In framing questions new facts can be introduced, while other questions will necessitate the drawing of rough sketches on the blackboard. For example, in revising the preparation of nitric oxide the apparatus should be sketched on the blackboard. Both the sketches and the labelling should contain several mistakes which must be corrected by the pupils. (Tests in which errors are shown to pupils are, however, condemned by some educationalists.)

Varied types of tests. The following is a selection of suitable examples:—

1. Insert the missing words: potassium and dioxide are used in the preparation of oxygen.
2. Approximately eighty per cent. of the air is
3. Lead monoxide is a basic oxide and carbon dioxide is an acidic oxide; write down three more examples of each type.
4. Cross out any of the following statements which are not true:—
 - (a) $\text{KNO}_3 + \text{H}_2\text{O} = \text{HNO}_3 + \text{KOH}$.
 - (b) Oxygen is the chief constituent of the air, and is present to the extent of seventy-five per cent.
 - (c) The symbol for hydrogen chloride is HCL .

5. Insert the missing words : since carbon converts lead oxide to lead, carbon is called a

6. Give two differences between sugar dissolving in water and zinc reacting with dilute hydrochloric acid.

7. All ammonium, sodium and potassium salts and all nitrates are soluble in water. All carbonates except ammonium, sodium and potassium are insoluble. Give a list of six salts which are soluble and six which are insoluble in water.

Other questions to be answered by summaries in column or chart form should be given. Examples are:—

Compare and contrast the preparation and properties of—

- (a) Carbon monoxide and carbon dioxide.
- (b) Carbon dioxide and sulphur dioxide.
- (c) Hydrogen and carbon monoxide.
- (d) The oxides of nitrogen.
- (e) The allotropes of sulphur.

Other questions might ask the pupil to—

1. Contrast in chart form the lead-chamber process and the contact process for the manufacture of sulphuric acid.

2. Show why the percentage of carbon dioxide in the air remains constant at 0.03 per cent.

3. Show how sodium chloride may directly or indirectly provide substances such as chlorine, hydrogen, oxygen, and the oxide, hydroxide, bisulphate, sulphate, bicarbonate and carbonate of sodium.

4. Illustrate by a diagram the relationships between the various compounds formed from calcium and carbon dioxide. (For example, see Figure 11.)

5. Draw up a chart showing the preparation and properties of all the common gases. (For example, see Figure 30, p. 164.)

Whenever possible questions should be based on local, topical or factual material. Pupils should be expected to study the implications of chemical facts which appear in newspapers and journals on, for example, mining disasters, explosions, poisoning cases; new water-, gas- or sewerage-undertakings.

Alternatively, pupils might be asked to draw graphs, or diagrams, representing the production and consumption of certain substances, using figures taken from reliable sources such as year-books and

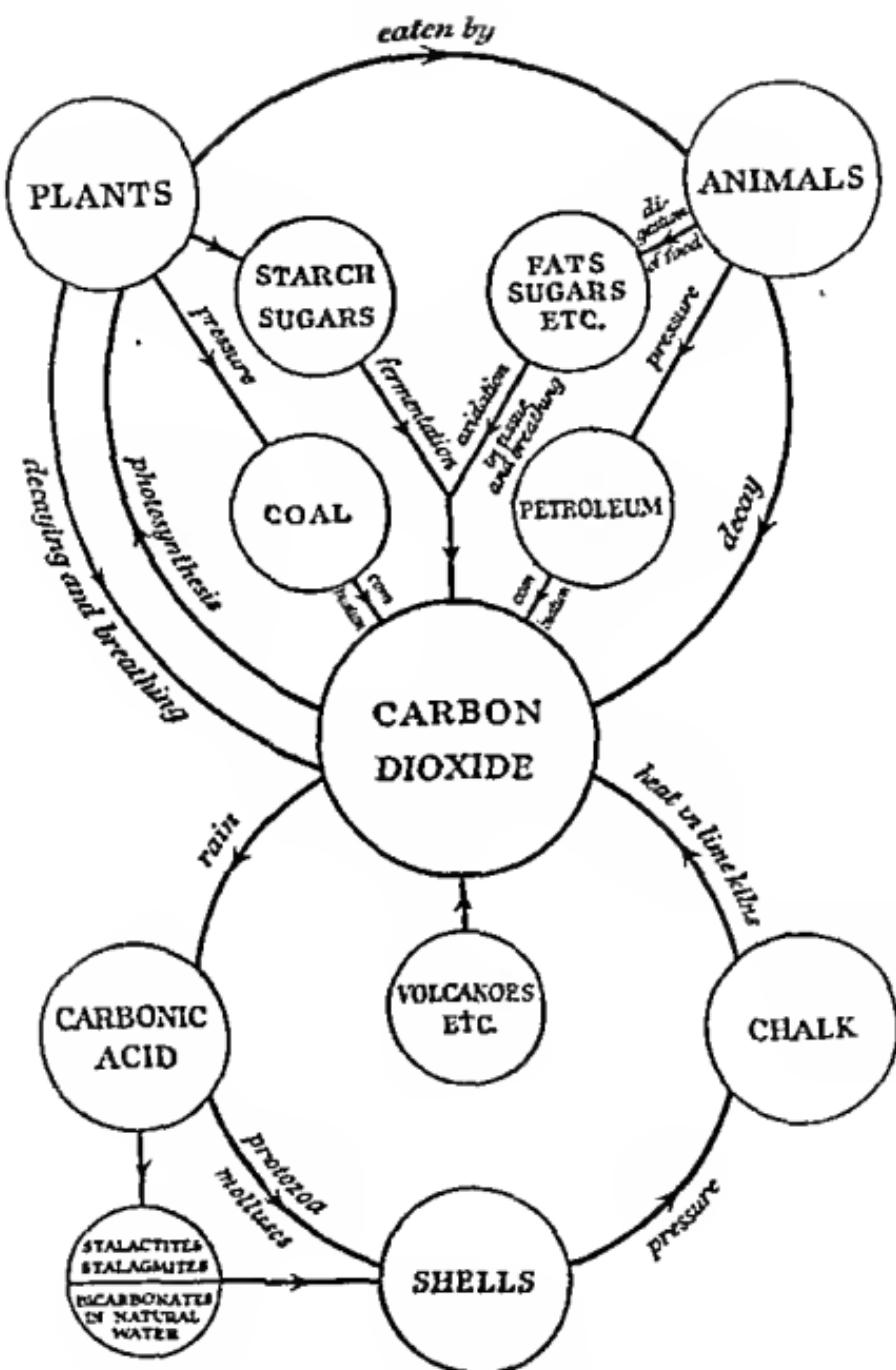


FIGURE 11.—The 'Carbon Cycle': a chart

government reports. It is a valuable exercise for each student to consider the economic and social questions involved in examples such as:—

1. Sources of sulphur for producing sulphuric acid.
2. The relative amount of sulphuric acid produced by the lead-chamber and contact processes during recent years.
3. Uses of sulphuric acid in industry and in different countries.
4. Questions, similar to the above three, on the manufacture and uses of nitric acid and ammonia and their salts.
5. Production figures for steels: relative production compared with other metals. Changes in production figures for aluminium.
6. Uses in industry of (a) different metals, (b) calcium carbonate, (c) quicklime.
7. Compare the figures quoted in 2, 4 and 5 above with those for your own country, or other countries, and with those for the rest of the world, and account for significant differences.

The following are some sample figures:—

SULPHURIC ACID (IN TONS OF 100 PER CENT. ACID), 1950

1. Production in Great Britain

Chamber acid	153,300 tons	Contact acid	289,700 tons
------------------------	--------------	------------------------	--------------

2. Amounts used

Superphosphate	102,000 tons	Ammonium sulphate	59,600 tons
Rayon and transparent paper	57,800 "	Paint and lithopone	39,100 "
Iron pickling	22,800 "	Dyestuffs	20,700 "
Hydrochloric acid	16,300 "	Glue and gelatine	16,300 "
Oil refining and petroleum products	15,100 "	Agriculture, sulphates, soap, glycerine, sewage purification and accumulators, etc.	95,600 "

Total 445,300 tons

3. Raw Materials

Sulphur and hydrogen sulphide	91,500 tons	Pyrites	45,400 tons
Speni oxide	47,100 "	Anhydrite	43,600 "

The following is another unusual type of problem¹:-

	Solubility at 20° C.	Solubility at B.P. of saturated solution	Boiling-point of saturated solution, °C.
Ammonium chloride	37.2	88.9	114.2
Barium chloride	35.7	60.1	104.4
Calcium chloride	74.5	325.0	179.5
Calcium hydroxide	0.165	0.05	100.0
Ferrous sulphate	26.5	177.8	102.2
Potassium carbonate	110.5	205.0	135.0
Potassium nitrate	31.6	284.6	114.5
Potassium sulphate	11.11	21.21	101.7
Sodium chloride	36.0	41.2	108.4
Sodium sulphate	15.0	43.0	103.4

Which of the following conclusions (1) are clearly indicated by the above data, (2) may be true but not proven, (3) are unsupported by the above figures?

1. The greater the weight of solute present, the higher is the boiling-point of a saturated solution.
2. All substances increase in solubility as the temperature increases.
3. Salts of potassium show the greatest increase in solubility with increasing temperature.
4. Sulphates have the lowest boiling-points with saturated solutions.
5. Chlorides have the highest boiling-points with saturated solutions.
6. The boiling-points of saturated solutions do not depend on the rates at which solutes increase in solubility with increase in temperature.

Little direct information on the above is given in the text-book, so the pupil receives excellent training in looking up facts and in the co-ordination of the knowledge so obtained.

Recent developments in testing Chemistry.—In recent years, especially in the U.S.A., the use of newer types of tests has been extended to Chemistry. Research has been concerned in devising, classifying and standardizing such tests so that they may be used for specific

¹ Taken from the 46th Year Book of the National Society for the Study of Education, Part I.

purposes. External examinations have their own specific purposes in assessing the attainments and abilities of pupils to enter a more advanced type of educational institution or to take a further examination. A teacher also requires such information but, in addition, wishes to measure a pupil's progress relative to others in his class. The teacher may also require diagnostic tests to find out which parts of the subject are learnt with ease and which with difficulty; if practical work has stressed particular aspects; and if the attainment level of the pupil corresponds with his intelligence-rating.

Some questions are set deliberately to test a pupil's knowledge of facts, his use of apparatus and his manipulative ability. Others may test his ability to apply chemical principles in solving problems. Teachers find that carefully devised questions may also be a most effective means of learning new work as well as of revising old work.

Classification of tests in Chemistry.—External examinations supply many questions of the essay or descriptive type: 'Write an account of . . .', 'Briefly describe . . .', 'What is the action of . . .?' It is not intended to classify such questions here, but rather to consider the newer type of questions which require shorter answers. Many of the latter tests involve little writing other than filling in blanks, or underlining or crossing out a word or phrase. It is, of course, advisable to use both types of tests. The shorter tests have many advantages, however, over the longer and older types of questions. They effectively cover a very wide field; they can be marked with precision since precise answers are required; they can be standardized and therefore used to compare the attainment of individual pupils or a whole class. A complete set of such tests may include one hundred questions, and forty or fifty of these should be of the true-false type. The test should occupy thirty minutes to be effective.

These tests may be classified under the following headings:—

1. *True-false type*.—Put T in the bracket if you consider the statement to be true, F if you consider it false.

(a) Air is a compound [].

(b) Hydrogen is a reducing agent [].

(c) Iodine is a liquid at room temperature [].

2. *Knowledge of facts or principles—simple recall type*.

(a) Why does a Bunsen burner 'back-fire', 'strike-back', or burn at the jet?

(b) Define the law of constant composition.

(c) When is sulphuric acid not manufactured from sulphur, air and water?

3. *Completion type*.—Copper and concentrated nitric acid form + +

4. *Matching type*.—In front of each of ten words in the second column put the number of the first-column word with which you think it is connected.

1. Sodium hydroxide	Non-metal
2. Potassium	Alkali
3. Red phosphorus	Slaked lime
4. Hydrochloric acid	Washing soda
5. Nitrogen dioxide	$\text{Fe}_2\text{O}_3 + \text{Al}$
6. Sodium carbonate	Metal
7. White phosphorus	Poisonous
8. Calcium hydroxide	Salt
9. Thermite process	Acid anhydride
10. Calcium carbonate	Dolomite

Calcite

Valency of one

5. *Multiple choice type*.—Cross out the statements which do not apply:—

(a) Carbon is (i) a reducing agent, (ii) insoluble in water, (iii) an acid anhydride, (iv) a non-metal, (v) insoluble in boiling sulphuric acid.

(b) The bromine in potassium bromide is removed or replaced by (i) chlorine, (ii) sublimation, (iii) carbon disulphide, (iv) iodine.

6. *To test reasoning powers*.—Select the best answer by crossing out statements which you consider are incorrect:—

Potassium chlorate is an oxidizing agent because (i) it contains chlorine, (ii) it is used in making matches, (iii) it contains oxygen, (iv) it evolves oxygen on heating, (v) its name ends in —ate.

7. *Varied types*.—These include the interpretation of diagrams, charts, graphs and statistics.

Note.—Arithmetical problems are discussed later (pp. 153, 187).

CHAPTER V

Organization of the School Laboratory

Stocking the laboratory

The problems which have been discussed in the previous chapters have been mainly concerned with teaching methods and technique. Much of the teacher's time, however, must be given to superintending the organization of the laboratory and making arrangements for classes to carry out their experiments smoothly.

Chemicals. — The list in Appendix C is the minimum for a course of the kind recommended in this book. Inorganic and organic substances are given separately, with the approximate quantities required annually by a school with 25 to 30 pupils in each class. Larger amounts may be needed in a school with two or more streams, if the practical work is to be done satisfactorily. Quantities can only be shown approximately because they will depend upon the experimental methods advocated by the teacher. It is advisable to keep in stock the amounts suggested, and to base the order for annual replacements on the stock-book records, which will supply exact information about the rates at which the chemicals are used.

The following points should be noted:—

1. It is generally cheaper to order large quantities of substances which do not deteriorate on keeping: e.g. copper sulphate and ammonium chloride can be kept in jars of 3 kilograms or 7 lb.
2. The three common mineral acids are ordered in concentrated form in Winchester quart bottles,¹ usually six at a time. The weights of concentrated acid, per bottle, are approximately: hydrochloric 3 Kg.; nitric 3½ Kg.; sulphuric 4½ Kg. As a rule it is best to use the 'pure' quality of acid. ('Fuming' nitric acid, in addition, may be required for work in organic chemistry.)

3. Care should be taken to order the physical form wanted in the case of each substance, and reference should be made to the catalogue of a reputable firm of suppliers. For example: pellets of sodium

¹ About 3 litres: see footnote on page 279.

hydroxide are preferable to flakes or sticks; bromine should be obtained in sealed tubes; deliquescent substances, quicklime, bleaching powder, etc., should be purchased in small bottles or tins.

4. Besides the ordinary stocks of certain substances, samples of a high degree of purity may be necessary for analytical work: e.g. sodium chloride, sodium bicarbonate, etc.

5. If a full course of qualitative analysis is to be followed, small quantities of substances representative of each group must be stocked. Further, organic reagents such as dimethyl glyoxime may be required.

Apparatus. — The list of basic requirements, given in Appendix D, is divided into three sections: (a) for the junior classes; (b) additional items for an advanced course; (c) some general equipment. Emphasis must be laid on the following points:—

(i) Many of the items in the first section of the list will be found in a general science laboratory, and they need not be duplicated even if Chemistry is taught as a separate subject in the junior classes.

(ii) Most of the items in section (a) will be required in, and will be suitable for, an advanced course. But the latter will need some special apparatus, as shown in part (b), and care must be taken to select the most appropriate types.

(iii) Section (c) of the list includes some tools, etc., which should form part of the normal equipment of any laboratory: they need not be obtained especially for the teaching of Chemistry.

(iv) Many pieces of apparatus can be made or improvised, and other items can sometimes be purchased locally.

(v) Quantities to be kept in stock will depend upon the length of time between the despatch of an order and delivery from the suppliers.

(vi) Quantities are not suggested in the list, for they depend on several variable factors: e.g. the size of classes, the number of pupils per class, the teacher's method of organizing practical work, etc. When every pupil in a class requires a particular item, it is easy to calculate the numbers to be ordered.

(vii) Some items will last for many years; others will be used up quickly. Accurate records in a stock-book should provide the information necessary for the ordering of annual replacements.

(viii) Great care must be taken to order the right types and sizes

of all equipment: e.g. corks and rubber stoppers to fit the flasks; glass- and rubber-tubing of suitable and corresponding diameters; troughs that fit into each other for storage, and gas-jars and covers of convenient size for use with them; bunsen Burners manufactured for the available gas-supply; etc.

(ix) It is advisable to try to standardize apparatus as far as possible, and it is therefore unwise to order too many different sizes of beakers, bottles, flasks, etc. In general, experiments by the individual and demonstration methods require respectively the smallest and the largest convenient sizes. (One large set of apparatus is needed for demonstrations. Sets of suitable apparatus must be purchased if micro-chemical methods are adopted.)

(x) It is economical in time and money to buy good apparatus: e.g. resistance-glass containers, best-quality porcelain, etc.

These points are considered more fully in this and later chapters.

The stock-book and other records.—Simple but systematic records should be kept of the apparatus and the amounts of chemicals in stock. The stock-book should have column headings such as date, number, size, type and quality of apparatus or chemical. Some teachers prefer a card-index to a book, and many education authorities have their own system of recording. The completed stock-book supplies most useful records for the Chemistry teacher. He can calculate the average yearly consumption of different apparatus and chemicals, work out the relative costs and breakages of apparatus supplied by different firms, or find out the durability of different qualities or different sizes of apparatus. The author prefers, for example, double surface condensers to Liebig condensers since they occupy less space, are more efficient in condensing vapours and there are fewer breakages. Squat beakers suffer less breakages than tall ones, silica evaporating basins less than porcelaio, good quality glass test-tubes less than cheaper glass—and the total expense is less.

Another useful device is to hang a small note-book and a 'wants-book' in the store-room or laboratory, so that masters, laboratory assistants and advanced students may enter up the name of any chemical or piece of apparatus which is not stocked but is required, or which will soon be used up.

Another type of reference book that ought to be available should contain such details as:—

1. Physical constants of commoner substances, including boiling- and melting-points, solubilities, densities.
2. Amounts of chemicals required to prepare (a) standard solutions for volumetric analysis, (b) solutions for reagent bottles, (c) special solutions, e.g. Fehling's solution, soap solution, Nessler's solution.
3. Recipes for cleaning glassware and metals, removing stains, freeing glass stoppers, fire-proofing, etc.

Finally, a small personal book for the teacher's own use should contain such information as:—

1. Contents of series of numbered stoppered bottles containing single substances and mixtures used in qualitative analysis.
2. Strength of solutions, purity of chemicals, alloys, etc., used in volumetric and gravimetric analysis.

If possible, substitutes for expensive chemicals should be provided, and the pupils or the laboratory assistant should construct some of the apparatus. Use should be made of local supplies. These may give inferior results, but they will have a wider and more intimate appeal.

The teacher will have to attend to, or at least supervise, the fitting up of a first-aid box, the labelling of all the stock bottles with reference numbers for an index, and the collection and labelling of Winchester quart bottles (or other suitably large bottles) for stock solutions of all the commoner reagents.

The storage of chemicals

The chemicals on the shelves in the stock-room or cupboards should be grouped in a systematic way. The commoner chemicals should be arranged so that all the compounds of one element are together. The elements are often arranged in alphabetical order. An alternative method is to arrange the elements and their compounds in the order in which they occur in the groups of the periodic table. A third method is to group all the elements, oxides, sulphates, nitrates and other similar compounds together.

Whichever method is used, it is an advantage to number each bottle or jar and to have an index book, so that any substance can be found

at a moment's notice. The bottles must be replenished periodically. All labels should be brushed over with melted paraffin wax in order to avoid fading and prevent deterioration, and to ensure permanent adhesion.

The reagent bottles should be kept in definite places on the benches or in the cupboards. For junior classes it is preferable to keep the laboratory benches clear and to hand out the reagent bottles as required. This is best carried out by storing the reagent bottles in wooden stands of suitable size. One stand might contain bottles of dilute hydrochloric, nitric and sulphuric acids, sodium hydroxide, ammonium hydroxide—all of twice-normal strength (p. 91)—and lime-water. Alternatively all the solutions of the same kind might be stored together.

Some teachers recommend a system of coloured bottles or bottles with spots of coloured paint so that it is possible to check at a glance if the reagent bottles have been replaced in the correct position. It is most advisable to have the same-sized reagent bottles with the same type of labelling—preferably sand-blasted.

Special precautions in storing chemicals.—Large bottles should be stored on the floor and not on shelves or benches, and it is an additional safeguard if Winchester bottles of concentrated acids are kept in buckets or dust-bins surrounded by sand. Bottles of inflammable liquids should preferably be stored in a cool outside building. With large amounts, the floor should be below the external floor level to prevent any spilt liquid flowing outside. Chemicals which react, for example concentrated nitric acid and either sodium or organic liquids, should always be kept apart. Periodic inspection of stored chemicals, as well as those in use, is necessary to ensure that stoppers are not blown out of bottles of inflammable liquids (e.g. diethyl ether and ethyl chloride), and to renew solutions to which sediments form (e.g. sodium phosphate and ammonium molybdate solutions).

White phosphorus is kept under water and sodium and potassium under mineral oil or petrol. Care must be taken in disposing of these residues either by burning the phosphorus carefully and dropping very small pieces of the sodium and potassium on water, or better still into methylated spirits, or by allowing them to stand in air in a safe and large container. None of them must be put in the waste-

box or in the sink. Chemicals such as sodium peroxide and the pentoxide and pentachloride of phosphorus should be kept in airtight tins. Small bottles of substances should be used if the substance is likely to be affected by the frequent opening of a tin or large bottle. In the case of sodium hydroxide, pellets are much preferable to powder, flakes or sticks.

Further notes on chemicals.—1. The following substances must also be kept in well-stoppered bottles:—bleaching powder, iodine, bromine, bromine-water, hydrogen peroxide, sodium amalgam, platinic chloride, lead acetate and carbon disulphide. Bromine and platinic chloride are best kept in small sealed test-tubes, which are opened only when required for use.

2. The following should be prepared as required—*aqua regia* (three parts concentrated hydrochloric acid and one part concentrated nitric acid), ammonium molybdate and sodium nitro-prusside solutions. Other solutions, e.g. sodium cobaltinitrite, slowly decompose.

3. The following should be kept in mineral naphtha or petrol:—sodium, potassium, iron wire and magnesium ribbon—the latter may be kept in waxed paper.

4. The following should be kept in water:—phosphorus and picric acid.

5. The following should be kept in a dark cupboard in a cool place:—ferrous sulphate, ammonium molybdate solution, ethyl iodide, phenol, aniline and glycerol.

Deliquescent and hygroscopic substances.—The relative humidity varies in different climates and affects chemicals to different extents. Exposure to damp air should be avoided as far as possible in the case of the following:—

ammonium acetate and thiocyanate; barium chloride, sulphide, and nitrate; bismuth salts (except carbonate); calcium oxide and chloride; chromium sulphate; cobalt chloride and nitrate; copper chloride and sulphate; ferrous and ferric chlorides; magnesium chloride; manganese nitrate; nickel chloride; phenol; platinic chloride; potassium carbonate, hydroxide and thiocyanate; soda-lime; sodium bromide, dichromate, hydroxide, iodide, nitrate

and sulphide; stanoous chloride; sulphuric acid; strontium bromide; zinc chloride and nitrate.

Efflorescent substances.—The following substances effloresce in dry climates:—ammonium carbonate; borax; magnesium sulphate; potassium ferrocyanide; sodium acetate, carbonate, phosphate, and sulphate.

Dangerous and expensive substances.—Concentrated mineral acids in Winchester bottles; metallic sodium and potassium; potassium chlorate and iodide; compounds of arsenic and mercury; silver nitrate; carbon disulphide; cyanides; ethyl alcohol; organic liquids.

These and any other costly or dangerous chemicals should be kept under lock and key.

Reagents.—Winchester quart bottles of all the common reagents should be kept full. Large schools may require aspirators with stop-cocks or large carboys. The common bench dilute reagents, such as acids and alkalis, should be of a uniform strength of twice normal. This system is the most convenient, and these bench reagents can be diluted by the pupils to any weaker concentration with a fair degree of accuracy. Special strength solutions of other reagents such as silver nitrate, barium chloride, ammonium thiocyanate and potassium ferrocyanide should also be available.

2N solutions of the commoner reagents.—Add the volume or weight given below to some water in a one-litre flask. Shake and then make up with water to exactly one litre. (Care is required in making up 2N sulphuric acid.) For larger amounts use a Winchester or carboy. First, using water, find the volume of the container, then calculate the volume of chemical required and mark this volume, using water, on the outside of a suitable vessel by means of gummed paper or with a marking pencil. Taking the figures below, for example, for concentrated nitric acid and a Winchester of volume 2,500 c.c., 318 c.c. of the acid are first added to the marked vessel and poured into a Winchester half-full of water. Water is then added to make this solution up to the 2,500 c.c. mark on the neck of the Winchester and the whole shaken thoroughly.

Acetic acid (glacial)	330 c.c.	Nitric acid	127 c.c.
Ammonium chloride	107 g.	Potassium bichromate	49 g.
Ammonium hydroxide	103 c.c.	Potassium chromate	97 g.
Ammonium oxalate	35.5 g.	Potassium ferrocyanide	211 g.
Barium chloride	122 g.	Potassium iodide	33 g.
Calcium chloride	35 g.	Potassium permanganate	3 g.
Cobalt nitrate	143 g.	Potassium thiocyanate	19.5 g.
Ferric chloride	90 g.	Silver nitrate	34 g.
Ferrous sulphate	20 g.	Sodium hydroxide	50 g.
Hydrochloric acid	200 c.c.	Sodium phosphate	120 g.
Mercuric chloride	27 g.	Sulphuric acid	56 c.c.

Slaked lime should be added to a Winchester of distilled water, so that a supply of lime water is always at hand. Distilled water must also be stored in large amounts if there is no still in the laboratory. Certain solutions such as sodium thiosulphate, ferrous sulphate, starch and potassium ferricyanide must be made up just before they are required, since they are unstable. Winchester bottles of standard solutions of acids, alkalis and potassium permanganate will be required for volumetric analysis. It is also convenient to have large volumes of saturated solutions of copper sulphate, ferric chloride, potassium permanganate, potassium dichromate, lead acetate, indicators, etc., made up for use with large classes. These can be diluted when required and then kept in reagent bottles or in large numbers of medicine bottles. The latter are recommended on the score of economy and ease of storing.

Storage and care of equipment

Adequate supplies of corks, bungs, rubber tubing, and hard and soft glass tubing and test-tubes must always be at hand. These enable the teacher to improvise most types of apparatus at short notice. Hard glass test-tubes can, for example, be used instead of flasks for the preparation of oxygen, and boiling tubes can be used to prepare sulphur dioxide and hydrogen. The composition of gases such as hydrogen chloride and sulphur dioxide can be determined by using test-tubes with the necessary fittings. Other experiments are given in Chapter VIII, where the advantages of unit pieces of glass tubing are discussed. Burettes can be joined by rubber tubing and used as a substitute for Hempel's burettes (see Figure 12) in equivalent weight determinations.

Much time and money can be saved by designing stands to hold

and store metal and glass apparatus and equipment. Large tripods and retort stands should always be put in the same place—one useful method is to hang them in a row upside-down on wire suspended underneath side benches or on strips of wood screwed underneath the side benches. Bunsen burners, filter and retort stands may be stored in a similar manner. Burettes and pipettes may be stored vertically in stands made in the wood-work room from two circular flat pieces of wood pierced with holes of the correct size and joined vertically by a length of wood through the centre of the circles of wood; the vertical piece also serves as a handle (Figure 13 (a)). Alternatively, pipettes and long glass tubing and rod may be stored horizontally, on shelves or in drawers, in grooves of wood running at right angles to the

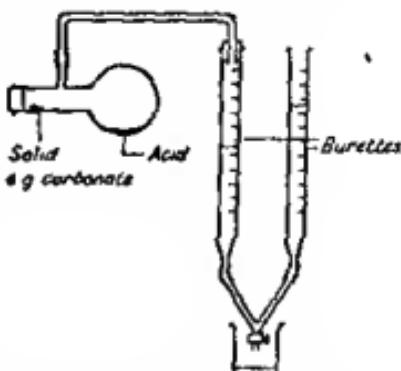


FIGURE 12.—The measurement of the volume of a gas (with a substitute for Hempel's burette)

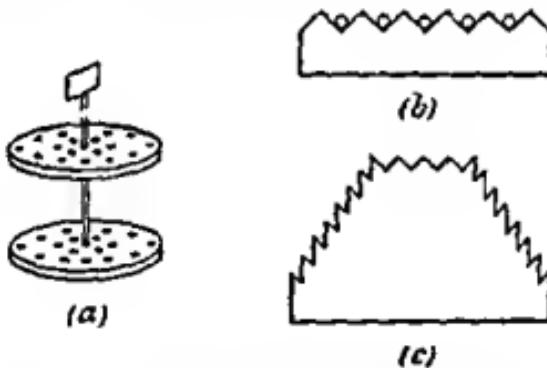


FIGURE 13.—Home-made equipment:

- (a) A pipette, or burette, stand (vertical)
- (b) and (c) Horizontal stands for glass tubes (as seen from the ends)

glass (Figures 13 (b) and (c)). Sand-trays may be kept in large biscuit-tins and sand in a bucket. Test-tube and burette brushes should be bung near the sinks.

Rubber tubing is best kept coiled in cool dark drawers.

Thermometers are best kept in their labelled cases in boxes packed with cotton-wool.

Flat trays which slide into cupboards or cabinets are most useful to store sets of apparatus, which may be lifted out as required. These are specially useful for sets of magnets, crucibles and crucible lids, crucible tongs, deflagrating spoons and beakers. Iron retort stands, tripods, clamps, bosses and rings should be thoroughly cleaned and painted regularly with aluminium paint (although consideration might be given to buying stainless steel or aluminium alloy stands).

If the laboratory is already well stocked, the teacher might consider the possibility of gradually acquiring larger and more expensive pieces of apparatus. In addition, specimen bottles containing samples should be collected. These might include the commoner ores, rare elements and compounds, and a range of well-shaped crystals.

Schools without a laboratory assistant or steward.—The case of the Chemistry teacher who is expected to look after the laboratory without any help provides complications. He should try to have his timetable arranged so that two parallel classes follow each other. This means that the same instructions, chemicals and apparatus can be used by each class. It will be necessary for the teacher to give up part of his interval or break, and devote time before and after school to preparing the material and setting up the apparatus. Fortunately, there are always boys and girls willing to help during these times. The best method is to appoint from each class two prefects or monitors, who come into the laboratory a few minutes before the lesson begins. Two other senior monitors might also be appointed to supervise the form monitors. Their duties should be to fill up the reagent bottles and place any special apparatus on the benches. Small samples of chemicals should be put out in watch-glasses or on pieces of paper. Sheets of glazed paper from old magazines or exercise-books should be cut neatly into quarters and either suspended by loops of string or stored in small boxes so that they are always available. They should always be used, for the purpose mentioned, in preference to more expensive filter-papers. In this way, pupils have most of what they need before them, and much time is saved at the beginning of the lesson. Where solutions are required in very

small amounts they may be absorbed in strips of blotting-paper; for example blotting-paper may be dipped in solutions of lead acetate, arsenic chloride and bismuth nitrate when experimenting with hydrogen sulphide. These strips are easy to distribute, easy to handle and also give satisfactory results.

Sulphur dioxide may be tested with litmus, potassium iodide, potassium permanganate and potassium bichromate solutions absorbed in blotting-paper: glowing string may be substituted for wooden splints in testing for oxygen or nitrous oxide. Small waste-boxes made from wood and lined with lead sheet or painted with bituminous paint, or even painted metal waste-boxes, should be placed at the end of each bench and emptied periodically by the pupils into larger waste-boxes kept in convenient places. Suitable sizes are length 12 inches, width 8 inches, depth 8 inches, and simple wooden or rope handles are an advantage. The corks and rubber bungs should be kept in separate compartments of drawers according to size. It is useful to have one sample of each screwed on to a board, with the appropriate size listed under each for reference purposes.

The teacher should have reagent bottles and chemicals in common use near at hand, and should keep a stock of apparatus in his own locker. Flasks can be kept fitted up ready for use. Apparatus which is required only occasionally, but which is difficult to set up, may be stored in cupboards. For example, the model used for the lead-chamber process in the manufacture of sulphuric acid should be always available. If there is a fume-cupboard near, and an electric plug on the side of the bench, much of the teacher's time is saved. It is also worth while designing special stands for storing a large variety of glass apparatus and similar essentials. Devices of this type, an adequate stock of chemicals, a large supply of solutions of the reagents, and a well-arranged time-table are the essential time-savers.

Schools with a laboratory assistant or steward. — It is unnecessary to stress the need for a full-time laboratory assistant or steward in school laboratories. Unfortunately trained assistants are often unavailable, and less efficient alternatives, either untrained adolescents or even pupils from the school, must be employed.

The chief duties of a laboratory assistant include the following, but he is expected to help at all times when required:—

1. Keeping benches and laboratory clean and tidy. Cleaning and drying glassware and cleaning out the sinks and drainage systems. Emptying main waste-boxes daily. Supervision of water-still and furnaces.
2. Oiling benches with linseed oil and turpentine, or ironing in wax. Polishing benches.
3. Drafting orders for chemicals and apparatus, checking supplies as they arrive, stock-taking.
4. Preparation of standard solutions for volumetric analysis, mixtures for analysis, stock-solutions for reagent bottles.
5. Keeping reagent bottles full.
6. Setting up apparatus for demonstrations and class experiments.
7. Replacing rubber tubing in burettes and aspirators. Greasing glass stoppers.
8. Replacing loose or damaged labels on shelves, cupboards and bottles. Covering labels with varnish or wax.
9. Keeping reagent bottles and chemicals in their correct places.
10. Periodic cleaning of metal stands, balance-pans, tongs, crucibles. Painting retort stands and lacquering balance pans.
11. Keeping the first-aid box replenished and keeping record of accidents and treatment.
12. Repairing glassware and apparatus; making and mending wood and metal stands.
13. Helping with projection of film-strips or films.
14. Ensuring that the laboratory is left safe at night. All Bunsen burners should be turned out, electricity and gas turned off, and no water taps left dripping.
15. Periodic checking of chemistry books in library and reference books in laboratory.
16. Making diagrams and charts; acting as demonstrator (depending on abilities).

The pupils' benches and drawers.—A well-arranged advanced laboratory must have a systematic arrangement of lockers and drawers. Laboratories are not always conveniently built for the large classes which have to be taught there, and the supplies of apparatus

are often insufficient. With elementary pupils it is advisable to keep all the apparatus either (a) on the floor—retort stands, filter stands, tripods, sand-trays and wire gauze in large tins, etc., or (b) on low open shelves—beakers, funnels, evaporating basins, test-tubes, etc. The pupils should be trained to collect the apparatus required, use it, clean it and return it to exactly the same place. A better method is to use a laboratory wall-bench to store the apparatus and to keep the floor free.

With advanced students each locker should be stocked with supplies for one student. The following should be supplied as a minimum:—test-tube rack (or improvised stand), three test-tubes (two 5-inch and one 4-inch), one evaporating basin, a test-tube brush, one small beaker, a Bunsen burner, a flame-steadier or wind-shield, a sheet of asbestos, a string duster or swab, Bunsen tubing, a retort clamp and ring, a wire gauze, crucible tongs, unit glass fitting for test-tubes (see Chapter VIII), a tripod, a burette stand, a retort stand, a piece of glass rod, a filter-sunnel and a piece of glass tubing.

One teacher suggests that a tray 15 inches by 11 inches should be used to carry much of this apparatus. Wooden pegs carry the test-tubes, beakers and flasks, and small compartments hold the crucible, crucible tongs, glass tubing, Bunsen burner and tubing, etc.

Pupils should know the proper place for storing other apparatus not kept in their lockers. It is also useful to have a labelled plan of the laboratory on the notice-board showing the positions of laboratory stocks, in addition to having clear labelling on shelves and cupboards.

Flasks, condensers, beakers, graduated cylinders and flasks, etc., should be stored in cupboards, and reagent bottles on shelves at the end of each bench—the concentrated acids standing in shallow porcelain troughs. Bottles of chemicals and the more expensive apparatus should be kept separately in the store-room.

More advanced students will require additional equipment, including 6-inch by 1-inch boiling tubes, burette (50 c.c.), pipettes (10 and 25 c.c.), burette brush, platinum wire, wash-bottle, mouth-blowpipe, charcoal block, ignition tubes, sand-tray, 2-inch watch-glass, and additional beakers and test-tubes. The student must be responsible for breakages and the cleaning of the apparatus. Deliberate disobedience and careless handling of apparatus should be dealt with severely. The rules of the school will decide to a large extent how

this is to be done. Payment of the whole, or part, of the cost should be made, or the article should be replaced by an equivalent value in some useful commodity such as matches or medicine bottles. The culprit might help clean up the laboratory; or, in a flagrant case, should be prohibited from doing experiments for a time.

Improvisation and substitutes

Chemistry students should be trained to be economical in the use of materials, to improvise by using scrap materials, and to provide efficient cheap substitutes for expensive equipment.

With junior classes enamelled beakers or suitable bottles should be used instead of glass beakers whenever possible. Medicine bottles may often be substituted for flasks or for reagent bottles. They are excellent for packing in cupboards. They should be labelled and filled, for example, with solutions of litmus, methyl orange, phenolphthalein, copper sulphate, potassium dichromate, potassium permanganate, and ferric chloride. Medicine bottles may be used in estimating the hardness of different types of water, or to collect filtrates, with a piece of glass rod or matchstick between the neck and the funnel to allow air to escape. Earthenware jugs may be used to carry large volumes of water, or dilute solutions, and are preferable to large beakers, especially for making up solutions of mineral acids and alkalis. Wooden pegs with strings or lamp-shade clips are excellent substitutes for test-tube holders, although a folded piece of thick paper is the most satisfactory. Small glass jars, or containers of pharmaceutical products, may be substituted for watch-glasses to hold small volumes of liquids or small amounts of solids.

Some home-made apparatus.—It is possible in advanced communities for an amateur chemist to obtain some of his supplies from home, and this fact should be pointed out to him. These supplies include washing soda, baking soda, tartaric acid, vinegar, lime, whiting, household ammonia, sal ammoniac, Epsom salt and Glauber's salt. A few substances, particularly the dilute acids and sodium bisulphate (used as a substitute for sulphuric acid), must be bought from the pharmacist's shop. Fortunately, there are a few simply written books to advise the beginner about experiments and purchases.

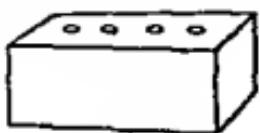
As cost is the primary consideration to most pupils, they contrive to make their own apparatus or to adapt kitchen utensils to their needs. Ingenious methods of heating are devised, such as fixing up a gas-burner with a tin base, or making an apparatus similar to that shown in Figure 6. Efficient spatulas or 'measures' are made from old rulers fashioned into the desired shape, or discarded small spoons are used. Platinum wires are replaced by lead pencils, or by silica rods from gas-mantles. Jars which have held jam, or other preserves, are used for bell-jars, and wide-mouthed bottles as gas-jars and flasks. The bowl of a clay pipe serves as a small retort. Old table-spoons or shaped local clay make good substitutes for crucibles, and pill-boxes for storing samples can be bought cheaply. A bottle can be cut so that the base serves as a beaker and the top as a substitute for a funnel. The metal tops of worn-out electric-light bulbs can be removed and the glass bulbs used as flasks; or, by careful heating, their bases can be flattened so that they serve as beakers. A plant pot can be cut with an old hacksaw so that the bottom part acts as a beehive shelf, and a tripod can be made by cutting a tin which has pressed sides. In fact, almost every type of apparatus can be replaced by an adequate, if unconventional, improvised substitute.

Taking the above remarks into consideration, it is apparent that the study of Chemistry at home should be given encouragement. Pupils are provided with a hobby, their knowledge of school work is extended, and their experimental technique is developed.

Improvised apparatus. — Solubility experiments can be improvised by using a large painted tin as a substitute for a thermostat, and having wooden or metal vanes driven by a water turbine. Several vanes are cut out and riveted on to a small cylindrical tin. This is carefully balanced and supported on an axle, and the whole enclosed in a tin or wooden box. A jet of water from a drawn-out piece of glass tubing strikes the vanes. The turbine can be suitably geared by the help of a few small wheels such as parts from 'Meccano' sets or other constructional toys. Some boys have a gift for making apparatus of this type.

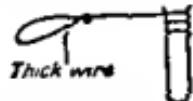
Useful retort stands can be made from wood with a fire-proof coating, or from 'Meccano' parts. Indeed, tripods, test-tube holders and mechanical stirrers and shakers can all be built up from

'Meccano' parts. In schools which possess metal- and wood-work rooms, numerous pieces of apparatus can be made if the necessary correlation can be arranged. Burette stands can be turned, test-tube racks of all sizes can be made (see Figure 14 (a)), wire can be bent to



Cardboard or wooden box
with front open

(a)

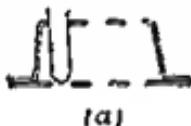


(b)

FIGURE 14.—More home-made equipment:

- (a) A test-tube rack (made from a box)
- (b) A test-tube holder (made from wire)

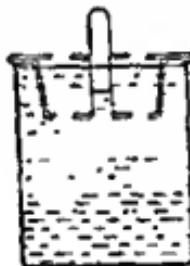
serve as test-tube holders (see Figure 14 (b)), and filtering stands and deflagrating spoons can be fashioned. Excellent combined test-tube racks and beehive shelves (see Figure 15), and small retort stands



(a)



(b)



(c)

FIGURE 15.—A piece of home-made apparatus, for use as:

- (a) A test-tube stand
- (b) A filter stand
- (c) A beehive shelf

The stand is made from sheet metal (e.g. from a tin). Different sizes can be made to fit standard size beakers, as in (c).

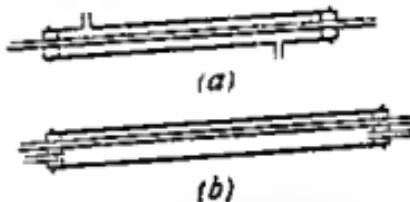
with adjustable clamps, can be made from sheet metal. A pipe-clay triangle can be made from a clay pipe-stem and wire; a blowpipe from a clay pipe, cork and piece of glass tubing.

Sturdy cooking vessels and disused tins may be used instead of the more usual apparatus. Tins may replace beakers or water-baths when flasks or test-tubes have to be surrounded by boiling water for heating inflammable liquids, e.g. in making soap from sodium hydroxide

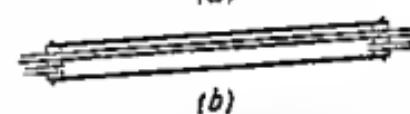
and fat dissolved in methylated spirits. Pieces of marble placed on a tin lid may be heated strongly with a blowpipe, or a roaring Bunsen flame, to yield quicklime. Two pieces of chalk held in wire gauze cages may be counterpoised on a length of wire with its middle part looped round a nail, fixed in a stand, to show that on heating one piece strongly it loses weight, forming quicklime.

Parts of the sides of tin cans may be cut out, leaving three legs, so that the whole serves as a tripod. A long metal tube, with two short tubes soldered near each end and carrying two corks and glass tubing, serves as a Liebig condenser (Figure 16). Tumblers, large ink-bottles, jam-jars and wide-mouthed bottles may be used in place of expensive gas-jars and beakers. Cleaned photographic plates provide slides for small-scale Chemistry; strips of brass may be bent to provide beehive shelves (Figure 15 (c)), or alternatively two holes may be made in small tins. Thick wire may be bent into a circular base and an upright to support magnesium, phosphorus or a candle, in combustion experiments. Scrap material such as scent-bottles, scent-sprays, pharmaceutical jars, clothes-pegs, wooden balls, metal foil and wire, spring-clips, large screws, old coins, discs, metal washers, broken U-tubes, condensers and glassware, should be collected and kept in drawers until required, since they may be readily adapted for useful purposes in science teaching. Lamp chimneys and old accumulator jars may often be bought cheaply and used as substitutes for more expensive apparatus. If a teacher doubts whether such improvisation is possible, he should ask pupils who have studied Chemistry for a year or two to suggest likely uses of certain scrap material as substitutes for the normal equipment. Opportunities to improvise should be presented as a definite part of the science course. Figures 17, 18, and 19 indicate further simple examples.

Many other examples are given in this book, and many of the pieces of apparatus can be made by the pupils themselves. Indeed after a few months' Chemistry it is a useful exercise to ask the pupils for ideas on improvising or designing apparatus as substitutes for

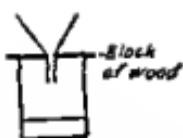


(a)

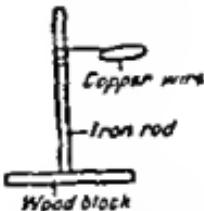


(b)

FIGURE 16.—Improvised Liebig condensers: two designs. The outer tube may be of metal or glass



(a)

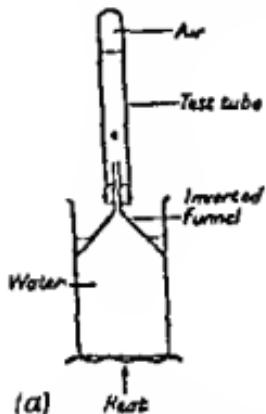


(b)

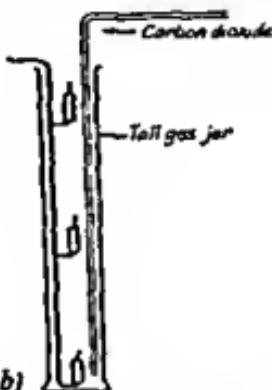
FIGURE 17.—Other improvisations:

(a) For a filter-funnel support

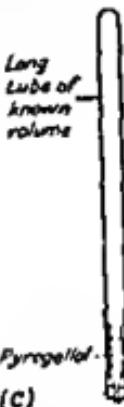
(b) For a crucible holder, etc.



(a)



(b)



(c)

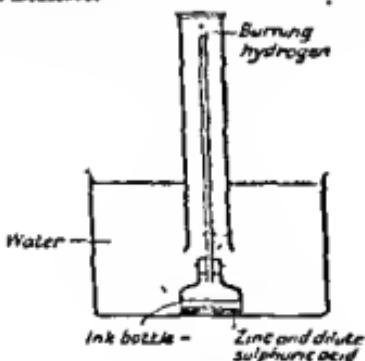
FIGURE 18.—Unconventional apparatus for experiments:

(a) To show that water contains dissolved air

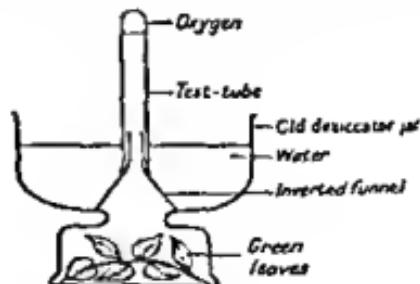
(b) To show the effect of carbon dioxide on burning candles

(c) To find the percentage volume of oxygen in the air

A little caustic soda solution is first shaken up in the long tube. Next the cork with tube of pyro-gallop is placed in position and the whole inverted several times. Then the cork is removed under water in a bucket, the levels are adjusted, and the remaining volume of air (length of tube occupied) is measured.



(a)



(b)

FIGURE 19.—More unusual apparatus:

(a) To show hydrogen burning in a limited air supply

(b) To show that plants evolve oxygen in sunlight

the orthodox type. Diagrams of such variations are shown in Figure 19.

Such experiments as the electrolysis of water, or of a strong solution of sodium chloride (as in the manufacture of chlorine and sodium hydroxide) (Figure 20), or electro-plating, can be done with the use of a few flashlight batteries or a wireless battery. Carbon electrodes can be made from the rods of old battery-cells, enclosed in U-tubes, jars or bottles. A unique example of home-made apparatus was brought to the writer by a boy whose father was an engineer: using waste pieces of brass and aluminium, chiefly from an old motor-car, they had constructed an accurate balance.

The amounts of substances to be used in experiments

The young teacher will find that in the early lessons instructions must be supplied to pupils about various experiments such as the preparation and properties of oxygen. Let us suppose that he has decided on all details except the amounts of the chemicals to be used and that, further, the demonstration is to be preceded by the pupils themselves doing experiments on the action of heat on various oxides and oxidizing agents. Small samples of different solids are given out to each pupil. Even with such small amounts, the teacher may decide that it is worth while finding out the minimum required by each pupil. If a glowing splint only is to be used for a test, much smaller amounts of solids will be needed than if large test-tubes are to be filled with the gas. In order to avoid waste, different amounts of different substances should be given out to provide the same volume of oxygen. One gram of the pure substances potassium chlorate, red lead, lead peroxide and mercuric oxide, for example, at S.T.P.¹ liberate, respectively, 275 c.c., 16 c.c., 47 c.c. and 52 c.c. of oxygen. In addition, the density of each solid will vary, so that very different volumes of each will give the same volume of oxygen.

A reference to text-books to discover what amounts to use will

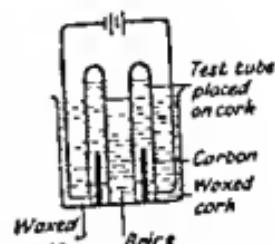


FIGURE 20. — The electrolysis of brine (small-scale)

¹S.T.P.—standard temperature and pressure (0° C. and 760 mm. of mercury). It is the same as N.T.P. (normal temperature and pressure).

often prove disappointing. Some may give the proportions, but very few give exact details of the weights of the reactants. 'Use a few grams', 'Cover the bottom of the flask', 'One-third fill a small flask', are common descriptions of the amounts to be used. The young teacher should avoid issuing such indefinite instructions.

Calculation of quantities to be used.—It is worth while setting problems of the following type to be discussed with more advanced pupils. They can calculate the volume of oxygen liberated from one gram of potassium chlorate and a little manganese dioxide, at room temperature and pressure. If necessary, students can consider the percentage purity of the potassium chlorate or the likelihood of securing a theoretical yield from it. More complicated questions on the formation of potassium permanganate and the solubility of the evolved oxygen in water may also be discussed. The main consideration should deal with the volume of oxygen required for specific tests. To illustrate this point, suppose the demonstration requires sufficient oxygen to fill five 200-c.c. gas-jars and five 50-c.c. test-tubes. The minimum volume of oxygen required is 1,250 c.c., but some allowance must be made for displacement of air, leakage and other losses. One gram of potassium chlorate liberates 275 c.c. of oxygen at S.T.P., therefore 4.56 g. of potassium chlorate will liberate 1,250 c.c. of oxygen at S.T.P. Thus, roughly 6 g. are required under these conditions to make allowance for losses and for variations in temperature and pressure. It is an instructive exercise for pupils to compare the amounts recommended in text-books with the quantities calculated as above.

The pupils can extend their investigations to the preparation of other gases. Sulphur dioxide introduces the complex action of copper on concentrated sulphuric acid. Ammonia introduces questions of using excess calcium hydroxide, and ammonium salts other than the chloride. A summary of the amounts of solids in whole numbers, which theoretically yield 3,000 c.c. of gas at S.T.P., is given in the chart, Figure 21. This volume should be sufficient for most experiments, but with poisonous gases it may be necessary to prepare smaller amounts. Approximate figures only are given to show the nature of the minimum weights required, and allowance may have to be made for impure chemicals.

1. Ammonia	8 g. ammonium chloride. 10 g. slaked lime.
2. Carbon dioxide	14 g. calcium carbonate, cover with water. 10 g. hydrochloric acid (30 c.c. concentrated).
3. Carbon monoxide	13 g. oxalic acid (or 7 g. formic acid). 14 g. sulphuric acid (9 c.c. concentrated).
4. Chlorine	12 g. manganese dioxide (or 9 g. potassium permanganate). 21 g. hydrochloric acid (63 c.c. concentrated).
5. Hydrochloric acid	8 g. sodium chloride. 14 g. sulphuric acid (9 c.c. concentrated).
6. Hydrogen	9 g. zinc. 14 g. sulphuric acid (9 c.c. concentrated in 80 c.c. water).
7. Hydrogen sulphide	12 g. ferrous sulphide, cover with water. 10 g. hydrochloric acid (30 c.c. concentrated).
8. Nitric oxide	13 g. copper. 34 g. nitric acid (38 c.c. concentrated in 40 c.c. water).
9. Nitrogen	10 g. sodium nitrate. 8 g. ammonium chloride with 50 c.c. water.
10. Nitrogen peroxide	5 g. copper with 17 g. nitric acid (19 c.c. concentrated), or 23 g. lead nitrate.
11. Nitrous oxide	12 g. sodium nitrate. 9 g. ammonium sulphate.
12. Oxygen	12 g. potassium chlorate. 3 g. manganese dioxide.
13. Sulphur dioxide	9 g. copper. 27 g. sulphuric acid (18 c.c. concentrated).

FIGURE 21.—Chart showing quantities of materials required for the preparation of 3,000 c.c. of the common gases.

The approximate amounts of chemicals theoretically required to yield 3 litres of a gas at S.T.P.—The pupils must realize that the quantities given above are calculated from the equations. The figures are provided in order to give some idea of the amounts theoretically required, but in practice larger quantities must always be used. The reasons for increasing the amounts are many:—

There are always losses owing to the need for displacing air from the apparatus, and to loss of the gas. Other factors which may make

for decreased yields will occur to the teacher. For example, when solids are heated in glass vessels it is usually impossible to complete the reaction and obtain quantitative results. Similarly, mixtures of liquids and solids cannot be heated enough to leave the dry mass necessary for maximum yields.

In the preparation of hydrogen it is obvious that, as the action proceeds, the amount of acid, and therefore the rate of the reaction, decreases to such an extent that the gas is finally evolved far too slowly for practical purposes.

Again, the reaction between concentrated hydrochloric acid and manganese dioxide proceeds slowly after the initial action, and chlorine continues to be evolved for nearly an hour after the beginning of the experiment. In order to speed up the formation of a gas in such a reaction, it is essential to add a larger quantity of one of the reagents.

In preparing sulphur dioxide, other substances, notably the sulphides of copper, form besides those represented in the usual equation. In preparing nitrous oxide, in order that an explosion may be avoided, all the ammonium nitrate must not be decomposed. Twice as much of the substance as is theoretically required is therefore used.

It is thus seen that molecular proportions of the chemicals are rarely used in the preparation of the commoner gases, and that it is advisable to add an excess of one constituent. In practice it is usual to place rather more than the calculated amount of the solids in the apparatus, and also, where necessary, excess liquid is added as required.

It is necessary for the teacher to keep a record of the quantities of the reactants which experience shows are most suitable for good results.

Amounts of substances required for other experiments.—In addition to the preparation of gases discussed above, other experiments are improved by using specific amounts of chemicals. The pupil must be told the weights of substances required for experiments on the preparation of sodium hydroxide (from sodium carbonate and excess calcium hydroxide) and of sodium bicarbonate (from sodium chloride, ammonia and carbon dioxide). Other quantitative experiments which are often spoilt because unsuitable quantities are used

include the determination of the percentage of carbon dioxide in calcium carbonate (see Figure 22), of water of crystallization in hydrated salts, and of oxygen in potassium chlorate. Pupils using abnormally large amounts are unable to complete the experiment in one practical lesson. In other cases an analysis may be worthless if excess of one substance is not used, and pupils should be shown how to calculate, for example, the quantity of standard sodium hydroxide required, not only to decompose a known amount of ammonium chloride, but to be sufficient for back-titration with standard acid.

In preparing salts the instructions are simpler, as 25 c.c. of the twice normal solutions of the bench reagents are usually suitable. Titration methods are used in neutralizing acids by alkalis. Metals and solid bases are added until they are in excess. This section could be extended and pupils asked to work out problems on similar lines to the above or the following:

(a) Weights of sodium chloride and concentrated sulphuric acid required to form 10 litres of normal hydrochloric acid solution.

(b) The weight of carbon required to determine the composition of carbon dioxide, using 150 c.c. of oxygen.

(c) The volumes of oxygen and hydrogen required to give 5 c.c. of water.

Unless special mention is made of the need for comparing practical results with the theoretical results calculated from equations, many pupils will fail to see the connexion between the two.

General rules for preparing substances.—Pupils should not be expected to learn the exact weights of chemicals required for the preparation of most substances. When such details are asked for, the pupils should either use reference books or be able to calculate the weights and volumes required.

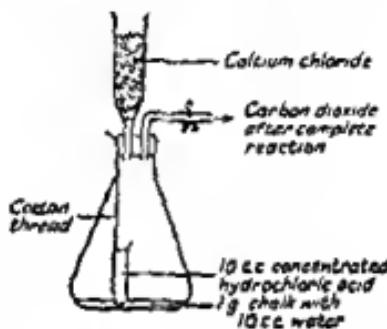


FIGURE 22.—Apparatus for finding the percentage by weight of carbon dioxide in chalk. The carbon dioxide must be replaced by air before the final weighing because the apparatus originally contained air

Alternatively, the approximate amounts might be remembered in a generalized form. This method is often used in text-books. Suitable types of apparatus and amounts of substances which illustrate this rough classification might be pointed out to pupils as follows:

(a) Kipp's apparatus or Woulfe's bottle. These should not be heated. (A filtering flask is stronger, has a wider neck and is therefore often preferred to a Woulfe's bottle, and sometimes to a distilling flask. It is doubtful if a Woulfe's bottle is ever necessary nowadays since it can always be replaced by a wide-necked flask.) Pour suitable acid as required on to excess solid to prepare hydrogen, carbon dioxide and hydrogen sulphide.

(b) Round-bottomed flask (but a flat-bottomed flask may be used when heating is not required) and thistle funnel fitting. Preparation of gases mentioned in (a), sulphur dioxide, carbon monoxide, chlorine, hydrogen chloride, nitric oxide, nitrogen peroxide.

(c) Equal weights of each substance:—ammonia, nitric acid and nitrogen.

(d) Small proportion of one substance required:—oxygen (four parts potassium chlorate to one part of manganese dioxide).

(e) End points:—shown by neutral points (acid and alkali); no further precipitation (with silver nitrate, barium chloride); colour change (potassium permanganate and potassium bichromate); gravimetric work (until constant weight); and no effervescence with carbonates.

Emphasis on the amounts used in these and similar preparations and reactions is much better for teaching purposes than relying on memory work or a practical laboratory manual.

Dangerous gases.—Atmospheric pollution should be avoided in the laboratory as well as outside. Unpleasant-smelling or poisonous gases should not escape into the laboratory. They should either be made in small amounts in the open laboratory with the necessary precautions, or be prepared in a fume-cupboard.

The question of danger to health suggests a reason for using minimum amounts when preparing poisonous gases. Great care must be taken in experiments using such gases as chlorine, carbon monoxide, hydrogen sulphide and nitrogen dioxide. After all the tests have been completed, the teacher should prevent excess gases being

liberated by causing them to be passed through delivery-tubes into suitable absorbents, since forty to fifty gas-jars of chlorine, for instance, in an average-size laboratory may be really dangerous. Pupils should be warned about breathing excessive amounts of dangerous gases, and where insufficient fume-cupboards exist, chemical treatment must be used to absorb the gases. After the preparation of chlorine in a class experiment, for example, a little sodium hydroxide solution should be poured into each gas-jar, and this should be well shaken and washed out. Sinks should be similarly treated.

Hydrogen sulphide should be absorbed in a solution of copper sulphate, and carbon monoxide in alkaline pyrogallol. It is often preferable to use a solution of hydrogen sulphide in water rather than to prepare the gas itself. It should be pointed out to pupils that the following parts of gas in 1,000 parts of air cause poisoning and perhaps death:—hydrogen sulphide 1, carbon monoxide 20, phosphine 20. Nitrogen dioxide and hydrogen sulphide are as dangerous as hydrogen cyanide (prussic acid). Such precautions keep the laboratory free from excessive amounts of dangerous gases. In tropical countries the laboratory often has a verandah, on which the poisonous gases can be prepared.

The cost of experiments. — Another factor to be considered is the cost of materials. If pupils use five times the amount actually necessary (and the figure is often higher) there is much needless waste of material; and wasteful habits are always to be condemned. With some substances, notably mercuric oxide and mercury salts, iodides, cobalt nitrate, and silver salts, there is an appreciable monetary loss. It should help pupils to be careful if they are told, for example, that potassium iodide costs 1s. 4d. and silver nitrate 4s. 4d. per ounce.¹

The teacher must consider the reason for using specific chemicals in school laboratories. The cheapest chemicals with the necessary properties should be used. These are usually soluble in water or they contain a specific radical. Thus, whenever salts or hydroxides are required, the soluble ammonium, sodium or potassium compounds are used.

Much instructive information about prices can be obtained from

¹ When mentioning prices, a teacher should try to quote those that the school has to pay at the particular time. *The prices given are only examples.*

a catalogue. Sodium chloride at 1s. 6d. per lb. is cheaper than potassium chloride at 2s. 5d. per lb., when a chloride is required. The former contains 61 per cent. and the latter 48 per cent. of chlorine.

Sodium salts are usually cheaper than potassium salts, but there are a few exceptions, notably sodium thiocyanate, sodium iodide and sodium permanganate, which are more expensive than the corresponding potassium salts. Again, potassium nitrate may be used in laboratories rather than sodium nitrate, although it is more expensive and contains a smaller percentage of the nitrate radical:—this is because impure sodium nitrate is hygroscopic, but it can now be obtained in a non-hygroscopic state. Pupils may be surprised to find that magnesium ribbon costs 2s. per lb., or that sodium costs 4s. 6d. per lb. The physical state—powder, wire, foil and ribbon—and the relative purity also determine the cost of chemicals, and teachers should only use the kind required. Pure chemicals are not often used in school qualitative experiments, and the extra cost for pure reagents may be quite unnecessary. For example, commercial granulated zinc may be listed, perhaps, at 3s. 2d. per lb. and pure granulated zinc at 4s. 6d. per lb. Other forms of this metal are:—dust at 1s. 7d.; sticks (commercial) at 2s. 5d.; foil at 3s. 2d.; granulated (arsenic free) at 5s. 0d.; sticks (arsenic free) at 5s. 6d.; sticks (chemically pure) at 4s. per pound. Foil and turnings are often economical for test-tube work because they are light in weight for their reacting surfaces. Supplies of each kind required should be kept in stock so that an expensive form will not have to be used when a cheaper one will suffice.

In more advanced experiments, especially in Organic Chemistry, the students themselves ought to be able to calculate the amounts of substances required to prepare substances such as ethyl chloride, nitrobenzene, *m*-dinitrobenzene, acetanilide, etc., and to note the reasons for using excess of one substance. (The actual weights of pure substances obtained, relative to the weights of substances which theoretically ought to be formed, give the percentage yields.)

In addition to the price of chemicals, it is necessary to bear in mind that pupils need help in deciding on the size and type of apparatus required. The use of large flasks may mean that there is not only a waste of chemicals, but that, if a breakage occurs, more expense is

entailed. Similarly, it is important that junior pupils should not be allowed to use expensive and sensitive balances, thermometers and measuring instruments, when cheaper and more suitable ones are available. Senior students, on the other hand, are often greatly handicapped by lack of a really good balance. Very accurate quantitative work could be done in schools—and time saved thereby at the universities—if a first-rate balance and some analytically pure chemicals were available.

The question of glassware, such as the advisability of ordering resistance types in preference to cheaper varieties, is discussed later.

It is often much cheaper to buy apparatus in large quantities; for example, test-tubes by the gross and beakers and crucibles in dozens. Crude common salt may be bought in a shop or market, red lead from the paint-shop, and quicklime and plaster of Paris from the builder: all quite suitable for many purposes in the laboratory. Good quality porcelain and glassware, however, is always preferable to cheap varieties. The diameter of glass tubing, thermometers and separating funnel stems should, whenever possible, be the same; and rubber tubing of appropriate sizes, and rubber bungs with suitable holes, should be kept in stock to avoid unnecessary delay. The grade of chemicals ordered depends on their uses, but 'pure' rather than 'commercial' quality should be bought, while for more advanced work chemicals of 'analytical' purity are necessary. A compromise should be made between the costs of the different grades, the amounts required, and the particular uses of the experimenter. School laboratories cannot always carry stocks of several grades of each substance.

Laboratory rules for pupils (to be obeyed in school and at home)

Danger.—1. Never use sodium, potassium, phosphorus or concentrated acids unless specially instructed. (All of these should be kept in a locked cupboard.)

2. Prevent outbreaks of fire. Do not put glowing pieces of wood or paper in the waste-box. See that the Bunsen burner does not 'burn back'.

3. Read the first-aid notice. If acids or alkalis get on your hands, clothes or bench, immediately wash with plenty of water, and then neutralize.

4. Do not taste chemicals without permission.
5. Do not mix chemicals aimlessly, nor carry out any experiments other than those definitely described by the instructions.
6. No apparatus or chemicals must be taken out of the laboratory.

Cleanliness.—1. Pour liquids only, never solids, down the sink.

2. Put all papers and solids in the waste-boxes.
3. Wipe down your bench and leave it clean and dry. Put the duster to dry.
4. Clean the apparatus you have used and replace everything in its proper place.
5. Replace the stool underneath the bench.

Expense.—1. Use the minimum amounts of substances.

2. Do not light the Bunsen burner, or other source of heat (or light), before it is necessary. Turn it off when no longer required.
3. Turn off the water-tap when not required.
4. Avoid waste of all kinds.

The efficient Chemist (notice to be displayed conspicuously in the laboratory).—1. His apparatus is neatly arranged on a clean bench.

2. He does not lay the stopper of the reagent bottle on the bench, but replaces it after use.
3. His test-tube is pointed away from himself and others in the laboratory.
4. His apparatus and locker are kept clean and tidy.
5. He labels anything which has to be put on one side to await further use.
6. He heats a vessel below the liquid level, and with care.
7. He not only reads the cuttings on the notice-board, but is on the look-out for information from every possible source.
8. He records all observations, measurements, weighings and results.
9. He disposes of waste materials (phosphorus, sodium, potassium, carbon disulphide, concentrated acids, etc.) with care.
10. He replaces reagent bottles and apparatus in their proper places.
11. He uses fume-cupboards to prevent the escape of poisonous

or unpleasant gases and vapours into the laboratory, and to avoid accidents from dangerous experiments.

12. He takes care to avoid breakages in apparatus: e.g. by not leaving pipettes sticking out from the bench.

Fire precautions

1. Take especial care with explosive reactions and inflammable substances.

2. Have regular fire-drills and, if possible, seek the advice of the local chief of the Fire Services.

3. Turn off main gas and electricity supplies at night, or if an accident occurs.

4. Keep the laboratory locked when not in use. Keep duplicate keys outside the laboratory in a glass-fronted cupboard (in case the originals are lost).

5. Test the fire extinguishers regularly (see page 114).

6. Keep buckets of sand for fires of organic substances. (The buckets should not be too heavy for pupils to lift.)

7. Have fire-proofed woollen blankets or asbestos blankets ready for immediate use in the laboratory.

8. Have strong glass screens for dangerous demonstrations.

9. Avoid contact of oxygen cylinder valves with oil or grease, and keep the cylinders upright in their stand.

10. Use asbestos sheeting on bench, and flexible metal Bunsen tubing rather than rubber tubing, if there is risk of exposure to much heat.

11. Heat inflammable liquids only in round-bottom flasks on hot-water or steam baths. Never use naked flames. Carry out the experiment in a fume-cupboard or with special precautions.

12. Keep only small amounts of inflammable liquids in the laboratory, and dispose of waste liquids with care. (Carbon disulphide may become ignited by an electric bulb or steam pipe, and diethyl ether by a hot-plate.)

13. Do not drop lighted matches, sodium, potassium or phosphorus into waste-boxes, and do not leave these solids in lockers or on benches.

14. Take care that a large round flask does not act as a lens when the sun's rays fall on it, as this may cause fire.

15. Isolate a small fire by suitable treatment: e.g. put an asbestos sheet over the mouth of a flask if alcohol ignites in it.

Fire extinguishers.—In addition to a fire-proof blanket, the laboratory should be equipped with fire extinguishers. The soda-acid type is suitable for burning paper and solvents such as alcohol, but not for burning sodium, magnesium, live electrical circuits or oils that float on water. The foam type is suitable for burning oils, and the carbon tetrachloride type for live electrical circuits. When the latter has been used the laboratory must be ventilated immediately.

First-aid in the laboratory

Reference should be made to Vol. VII for general information on first-aid in Science rooms. Below is given an outline of first-aid treatment suitable for accidents which may occur in a Chemistry laboratory. The list is a long one, but a young teacher should note that most of the items are included as a warning. With carefully-trained pupils, avoidance of unnecessarily dangerous experiments, emphasis on the need to avoid pollution of the laboratory atmosphere, routine checking of apparatus and equipment to avoid blocked tubes, and ensuring that joints are air-tight and the apparatus correctly used, accidents should be rare. The number of serious accidents occurring in a well-run Chemistry laboratory is negligible, but it is wise to keep particulars of even minor injuries. Serious cases should receive prompt attention from a doctor. When in doubt, it is wise to send the injured pupil to the doctor. It should be remembered that a teacher of Chemistry is only expected to give first-aid treatment, but this should be given promptly and effectively.

Burns from acid.—Either (a) put on a pad of solid sodium bicarbonate, or (b) immediately run much water on to the burn, and then wash with weak sodium bicarbonate or borax solution. Treat as a burn.

Burns from alkali.—Wash with running water and then with weak acetic acid or lemon juice. Treat as a burn.

Burns from bromine.—Wash with weak sodium bicarbonate solution, then with alcohol. Dry, and treat as a burn.

Burns from phosphorus.—Wash by immersion in water. Cover with cotton-wool soaked in bench silver nitrate solution. Treat as a burn. (Send for doctor if possible.)

Poisons.—The general principle should be to call a doctor immediately after giving suitable treatment as follows:—

(a) for gassing: remove the patient from the laboratory into fresh air, give hot coffee as a stimulant, and suitable treatment as below;

(b) for poisoning: give appropriate treatment as below. In general (i) with corrosive poisons (indicated by burnt lips and mouth from acids, alkalis and zinc compounds), do not give emetic, but treat the patient with white-of-egg or large quantities of milk, rice-water or barley-water, as demulcent or emollient; (ii) with non-corrosive poisons give an emetic of one tablespoonful of common salt, or one teaspoonful of mustard, in a tumbler of warm water.

(A) *Acids and alkalis*.—(a) Concentrated hydrochloric, sulphuric, nitric and acetic acids. Spit out, and rinse the mouth with much water. If swallowed, send for a doctor and let the patient drink milk of magnesia, 5 per cent. sodium bicarbonate solution, or a suspension of calcium carbonate and demulcent. Avoid emetics or purgatives.

(b) Oxalic acid. Neutralize with milk of magnesia or a suspension of calcium carbonate (not potassium or sodium carbonate, and do not give much water). For oxalates, and as emetics for oxalic acid, use mustard or zinc sulphate.

(c) Carabolic acid (phenol). Solutions of zinc sulphate, mustard or magnesium sulphate should be given as emetics, with large amounts of water to drink.

(d) Strong alkalis, e.g. hydroxides of sodium, potassium or ammonium. Spit out and rinse the mouth with much water. If swallowed send for a doctor, and neutralize with weak solutions of acetic acid, citric acid, tartaric acid or lemon juice. Give demulcents, but avoid emetics.

(B) *Gases and vapours*.—(a) Carbon monoxide (or coal-gas). Take the patient into fresh air. Give oxygen (if a cylinder is available) mixed with air, or put a tube from a carbon dioxide generator near the nose. Send for a doctor.

(b) Chlorine and bromine. Smell methylated spirits, alcohol or ammonia. Rinse out the mouth with sodium bicarbonate solution.

(c) Chloroform and nitrous oxide. Keep the patient awake and conscious by shouting and shaking. Give stimulants and artificial respiration. If chloroform is swallowed, give zinc sulphate emetic.

(C) *Other poisons* (see list, p. 117).—I. Iodine. Give emetics, and large quantities of starch 'solution', e.g. arrowroot, barley- or rice-water, to drink.

2. Compounds of metals:

(a) Copper compounds. Encourage vomiting, give rice-water or white-of-egg in warm water. Give barley-water or rice-water later.

(b) Lead compounds. Emetics, then magnesium sulphate or sodium sulphate.

(c) Mercury compounds. Mustard emetic. White-of-egg, rice or starch mixed with water. Demulcents and stimulants.

(d) Silver compounds. Strong solution of sodium chloride, then mustard emetic.

(e) Zinc compounds. No emetics, give demulcents. Large quantities of dilute sodium carbonate solution.

3. Arsenic compounds. Emetic of zinc sulphate or sodium chloride solutions. Follow by demulcents.

4. Cyanides (including prussic acid). Apply artificial respiration. Send for doctor.

5. Phosphorus. 200 c.c. of 0.2 per cent. copper sulphate solution, and mustard emetic.

(D) *Eye injuries.*—Apply treatment as below, and then take the patient to a doctor unless the accident is slight. After treatment, drop castor oil or eye-drops in the eye, and bandage to keep out the light.

(a) Mechanical. Remove the foreign body by lifting the eyelid lightly over a matchstick so that the eye can be examined. Use a camel-hair brush moistened with glycerine, or open the eye in warm water in an eye-bath.

(b) Alkalies. Particularly dangerous. Blow a gentle stream of a saturated solution of boric acid into the eye. Then treat as above.

(c) Acids. Blow a gentle stream of alkaline eye-wash of borax solution into the eye. Treat as above.

The first-aid outfit.—A list of the suitable contents for a first-aid cupboard or box is given in Appendix E, p. 289.

Dangerous chemicals and experiments

A. *Inflammable or explosive substances.*—Hydrogen, phosphine, coal-gas, hydrocarbons, aluminium chloride, silver azide, silver nitride, carbon disulphide, phosphorus, ether, alcohols, benzene, acetone, picric acid, and many organic substances. These may cause

explosions when mixed with air and ignited. Mixtures containing oxidizing agents such as picrates, nitrates, peroxides, chlorates and manganates must always be treated with care.

Mixtures of powdered magnesium or aluminium with sulphur or oxidizing agents may explode on heating. On occasions explosions have taken place with water and impure sodium peroxide. Carbon disulphide vapour, in a sink for example, may form an explosive mixture with air. Explosions may be caused by naked flames or electric sparking. Dangerous chemicals should be mixed in a wooden mortar. If necessary an experiment should be carried out behind a thick glass screen using goggles and asbestos gloves.

B. *Poisonous substances.* —

Aldehydes.	Iodine.
Ammonia.	Lead compounds.
Amyl nitrite.	Mercury metal, vapour and compounds.
Aniline and amino compounds.	Nitric acid (concentrated).
Antimony compounds.	Nitrobenzene and nitro-compounds.
Arsenious oxide.	Nitrous oxide.
Arsenic compounds.	Oxalic acid and oxalates.
Barium compounds.	Permanganates.
Bismuth salts.	Phenols.
Benzene.	Phosgene.
Bromine.	Phosphine.
Bromoform.	Phosphorus (white).
Carbon disulphide.	Potassium hydroxide and permanganate.
Carbon monoxide.	Pyridine.
Carbon tetrachloride.	Sodium hydroxide.
Chlorine.	Silver salts.
Chloroform.	Sulphur dioxide.
Coal-gas.	Sulphuric acid (concentrated).
Copper compounds.	Tin compounds.
Cresols.	Toluene.
Dimethyl sulphate.	Zinc compounds.
Ethers.	
Hydrogen cyanide and cyanides.	
Hydrogen sulphide.	

Many of the above are not 'scheduled' as poisonous, but they should nevertheless be kept in locked cupboards.

Various devices might be used to prevent accidents with bottles of poisons. Red poison labels should be stuck on, the label should be read before and after removing the cork, or a small bell might be placed round the neck of the bottle, or a pin stuck in the cork.

C. *Causing burns on skin.*—Concentrated acids and alkalis, sodium, potassium, phosphorus, carbolic acid, hydrofluoric acid, bromine, chromic acid, glacial acetic acid, and phenylhydrazine.

Dangerous reactions.—Experienced teachers realize that pupils sometimes obtain dangerous chemicals from external sources, and warn them against the use of such substances as the following, which can occasionally be bought from pharmaceutical chemists: phosphorus, oxalic acid, potassium cyanide, mineral acids, and the alkalis.

Pupils occasionally attempt to prepare picric acid, nitrogen iodide, nitroglycerine and mercury fulminate without special precautions, or try the action of poisons on live animals. Every precaution should be taken to prevent pupils from securing samples of the dangerous chemicals mentioned, and from repeating dangerous experiments at home.

Occasionally in junior work, but more often in advanced Chemistry, the following experiments may be done. A definite reference to, and warning of, the danger entailed should prevent dangerous accidents.

1. Rubbing or warming an oxidizing agent (such as potassium chlorate or potassium permanganate) with carbon, sulphur, phosphorus, powdered metals such as magnesium or aluminium, organic substances, or concentrated sulphuric acid.

Such experiments are best omitted from pupils' individual or group work. Practical Chemistry text-books describe the precautions to be taken.

Similarly, it is advisable to carry out the preparation of oxygen in a test-tube, with small amounts of potassium chlorate and manganese dioxide, before the large-scale demonstration is done, in case the manganese dioxide contains any carbon or organic substances.

2. The pouring of water into concentrated sulphuric acid, or pouring the hot concentrated acid into a wet sink, causes many serious accidents in the laboratory.

3. The warming of strong solutions of the alkalis with aluminium

powder, as well as other reactions, may become uncontrollable and spurt out concentrated acids or alkalis on person or bench.

Other dangerous reactions or occurrences are:—

4. The action of concentrated nitric acid on alcohol or turpentine, or the process of nitration.

5. The burning of hydrogen or arsine (Marsh's test) at a jet. (First test for the removal of air by collecting and lighting a small test-tube full.)

6. The dropping of sodium or potassium into water. (Always scrape off the brownish incrustation, and use small amounts when immersing the metal under water. Even the smallest pieces sometimes explode unaccountably.)

7. The heating of ammonium nitrate. (Avoid overheating.)

8. Reactions involving poisonous gases either in preparations or qualitative analysis. (See list, p. 117). (Oxalates and formates with concentrated sulphuric acid evolve carbon monoxide, and ferrocyanides and dilute sulphuric acid evolve prussic acid.)

9. The 'sucking back' of water in the preparation of a soluble gas, such as hydrochloric acid, or the blocking up of a delivery tube.

10. Fumes and splashing from organic substances, such as nitro- and amino-derivatives.

11. The reaction between ammonia and chlorine.

12. The smouldering of a charcoal block after a reduction test.

13. The treatment of solid alkalis with concentrated acids.

14. The explosion of acetylene and air, or chlorine and hydrogen.

CHAPTER VI

The Relative Merits of Individual and Demonstration Methods

Both demonstrations by the teacher and individual laboratory work by the pupil are essential in teaching Chemistry. The problem is to determine the proportion of each to be included in the course. Little accessible research work has been done in this field to guide us, but the Americans have begun some useful work in this direction. Guiding principles must be based on standardized tests. In these tests adjustments must be made for such variable factors as the type of pupil and teacher, the conditions of the laboratory, and the subject-matter of the lesson.

Individual experiments—examples in detail

From 1889 onwards Professor H. E. Armstrong advocated the heuristic method (see page 122) as a special individual approach, and its adoption brought a definite improvement in the methods of teaching Science in schools. Armstrong's method trains the pupil in initiative and develops self-reliance, good judgement and manipulative skill, by personal contact with apparatus and material.

Such individual work is particularly valuable where the pupil is set to solve practical problems which have been arranged round a central project. This is very often the case with Chemistry, which offers special and excellent opportunities for this type of work. In such problems, the pupil's power of observation is developed, he learns to handle materials correctly, he alters the conditions of his experiment and notes any change, he applies the knowledge he has already acquired, and he reasons from the new facts. It is impossible for the pupil to gain the full benefits from a series of practical experiments unless he is personally interested, and unless he himself sees the changes occurring.

The following examples give suitable practice in this type of individual work. Each series is merely outlined, and the actual instructions given to the pupil are not reproduced. Each pupil carries out as

many exercises as possible, but the whole of the series is done by the class.

(a) *Calcium carbonate*.—Examine the physical properties of, and the action of the three dilute mineral acids on, various substances containing calcium carbonate. Use marble, limestone, chalk, calcite, coral, mother-of-pearl, egg-shells, sea-shells, snail-shells and stalactites or stalagmites. Describe the colour and hardness of each. Use the three mineral acids to find out which substances evolve most carbon dioxide. Compare the action of the acids and account for any differences. Find out which form of calcium carbonate and which acid are best for preparing carbon dioxide in the laboratory. Explain why dilute sulphuric acid is exceptional. Repeat the tests for carbon dioxide.

Heat strongly by means of a blowpipe a small piece of marble suspended in a coil of nichrome wire. Note the powder formed and the incandescence. Cool. Allow one drop of water to fall on the powder on the palm of the hand. Note the heat evolved and show that the powder was calcium oxide. Shake the product with water in a test-tube and so form milk-of-lime. Note the action on litmus. Filter, dilute and blow through the clear lime-water to prepare calcium carbonate. Test for the calcium carbonate.

(b) *Alkalies*.—Obtain small amounts of sodium hydroxide and potassium hydroxide (caustic), washing soda (sodium carbonate), 'household ammonia', soap powders, ashes from wood and seaweed (containing carbonates of sodium and potassium), quicklime, etc. Describe the source of each, special everyday uses and physical properties. Find out if soluble in water, note the action on indicators, the feeling when rubbed between fingers and the effect on cloth. Shake and warm with fats. Do typical tests for common alkalies. Note differences.

In all these experiments, and in others of the same type, keen individual observations of slight variations in the changes, and careful recording of facts, are essential. The more difficult work of noting the exceptional reactions, co-ordinating data, and generalizing from collected facts must again be an individual matter.

It should be noted that the findings of twenty to thirty individuals are of vital importance in obtaining good results in quantitative analysis. Such a number means that a more reliable average can be

obtained. Thus, the percentage of carbon dioxide in calcium carbonate, problems in volumetric analysis, the volume of oxygen given off from a known weight of potassium chlorate, and the determination of equivalent weights, may all be determined much more accurately when the average result of a class is taken. When all the figures are put on the board, the class can decide if an individual result is unreliable. A discussion of the comparative accuracy of the average will emphasize the advantage of using the results of a number of individual experiments instead of one demonstration. The average of a class indicates constant errors inherent in the method.

The outstanding value of obtaining results which depend on the united efforts of the whole class is shown in an experiment such as plotting a solubility curve. Each pupil carries out his experiment at a certain fixed temperature, and the final curve summarizes and checks all the individual results. No satisfactory substitute for such work could be provided by a demonstration.

The heuristic method in its elementary stages

History.—As early as 1790, Priestley suggested that Chemistry should be introduced as an educational subject, and that teaching methods should be based on investigation, so that the learners themselves discovered the facts. Pestalozzi, Locke and Rousseau were other pioneers who advocated similar teaching methods. Pestalozzi held that the individuality of the child must be sacred to the teacher, and that investigation is the best method of learning facts. He thus anticipated the principle to be discussed in this chapter, as he believed that children should be put on the road which the discoverer of the subject himself took. Rousseau's method also foreshadowed the heuristic method. He urged that the child should not learn Science by memorizing lists of facts, but that he should be led to discover principles on his own initiative. H. E. Armstrong, about 1889, was the first to introduce the heuristic theory into the teaching of Chemistry and Physics, and Great Britain seems to have been the only country in which this development took place.

Benefits of the heuristic method.—Armstrong considered that Chemistry lessons should be made up of definite tasks. These should be in the form of problems which each pupil works out

experimentally. The following quotations describe the principles of the heuristic method:—

'Every Science lesson should be in the form of an inquiry. Work is only scientific when it springs from a desire to know from our own knowledge some definite thing concerning which our curiosity has been moved.'

'A boy must use his eyes, as knowledge is only of use when it is obtained from personal observation. The pupil, rarely, if ever, uses a text-book, and he should be put in the position of the original discoverer.'

'Young children are delighted to be told that they are to act as a band of young detectives. In studying the rusting of iron they are told that a crime has been committed on the valuable and strong iron to change it into brittle dust. They are interested to find out if it is murder (something outside the iron), or suicide (changes on its own accord).'

'Problems must be carefully graded and the pupils should be allowed to walk around the laboratory and get help from their companions. Quantitative work should be introduced quite early in the course. The balance is the most important piece of apparatus, and it is to be regarded as an instrument of moral culture to be treated with the utmost care and reverence.'

It must be noted that Armstrong's methods are occasionally misunderstood. His idea is not that the pupil should discover the *cause* of a reaction but that he should find the general conditions under which it occurs.

The knowledge acquired by correct use of the heuristic method is thorough, for all the information is obtained from direct contact with apparatus and chemicals. Independent and individual endeavours are the basis of learning. Interest is aroused in common objects, as well as in natural phenomena. Pupils learn to balance and weigh words and phrases as well as objects. Armstrong claims that specific benefits are derived from his methods, which develop moral and intellectual character. The peculiar advantage of the heuristic method is that it encourages the young research worker (the pupil) to develop the attitude of the experienced research worker, by carrying out experiments under similar conditions.

Before the introduction of the heuristic method, most Science teachers thought it better to avoid, rather than to overcome, practical difficulties. If they allowed experimental work at all, the pupils merely repeated demonstrations or carried out routine tests, and little attempt was made to develop in them an understanding of scientific methods and ideals. The procedure of the heuristic method differed in every respect. It was fortunate that the new method was introduced, since its activity was much preferable to the didactic statements and passive observations of the lecture-room. It should not, however, be assumed that it was accepted in its entirety by all schools where Science was taught, but the methods of most teachers were definitely influenced by the principles of the heuristic method. In elementary schools and adult classes, however, some real harm was done by the introduction of this method. It was impossible to provide the necessary laboratories and the large quantities of apparatus and chemicals required for the new individual methods: consequently Science was discontinued in many of these institutions, and the existing equipment gradually deteriorated.

Criticisms of the heuristic method.—The heuristic method is criticized from several points of view:—many inspiring, historical experiments which emphasize the romance of Science are put into the background. Special types of apparatus which can only be used in demonstrations are neglected, and certain experiments, requiring the skilled technique of a teacher, have either to be omitted or are unsuccessfully performed by the pupils.

The heuristic method lacks vitality, since it concentrates on the arrangement of facts and a systematic training in experimental methods. These alone are unsatisfactory. The enthusiasm and personality of the teacher who arranges the lessons to suit his own ideas have much more appeal and are more likely to develop a love of Science in the pupils. Whilst the heuristic method encourages perseverance, it is tedious for a young pupil to continue a prolonged search on one subject only. The problem experiment which is lively, and has repeated surprises, is of more benefit from an educational point of view.

The method cannot be applied to the discovery of fundamental chemical laws. These can only be verified or illustrated. Furthermore,

the findings of both psychologists and teachers show that pupils of 10 to 15 years cannot study Chemistry in the same systematic way as those of 15 to 18 years, whilst Armstrong and his followers maintained that, whatever his age, the pupil had the capacity for systematic reasoning, and that he would develop this without the influence of a teacher.

The heuristic method is effective when a great deal of time is devoted to one small section of the Chemistry course, but it is unsuitable in these days when general principles are taught. Again, some pupils are familiar with more chemical facts than others. In a practical problem, some know the result before the experiment is begun. For example, in one school, parallel classes which had completed two terms' Chemistry were to begin experiments on the composition of water. A written test was given asking which elements were present in water. Twenty-one out of sixty knew that water was made up of oxygen and hydrogen, and seven pupils knew its formula.

Probably most criticism centres round the idea of putting the child in the position of the original discoverer. Theoretically, this idealistic scheme is attractive, but it is not possible in practice. Unlike the adult research worker, the pupil is not necessarily of high intellectual power, and he has not had the necessary intensive training. Pupils cannot be expected to discover all the relevant facts, for even outstanding chemists must take advantage of the work of their predecessors. Hales's work helped Priestley, and in turn Priestley's work helped Lavoisier. After years of labour, these great men succeeded in solving a few problems only. Modern research chemists use the catalogued information of earlier workers, and individual investigation tends to be replaced by the 'team-work' of a whole laboratory.

Unlike an experienced chemist, a pupil cannot be expected to know the difference between facts which will help his particular problem and those which may be interesting and unusual but irrelevant to his immediate problem. Fundamentals must be acquired before even the beginnings of research are possible, and the pupils' time is much better spent in learning these necessary facts and principles. There is not sufficient time given to school Chemistry for a pupil to re-discover all the facts he must know about the simpler parts of the syllabus. His own experiments should provide a material foundation for the chemical knowledge which he acquires, but this

should be supplemented by demonstrations, class discussions, accounts from text-books, and facts and data from reference books. Most teachers agree that if the heuristic method is attempted, it should be modified so that help can be given to the pupils when necessary. Thus, much time is saved and many benefits are gained. It is found that even with graded exercises some pupils often come to a dead-end and, in order to avoid any mental dissatisfaction and waste of time, sufficient aid should be given to enable them to continue their work. A helpful suggestion or an apt analogy will not destroy the spirit of discovery.

The heuristic method has also been criticized on the score that, in practice, it is not really a discovery or re-discovery method, as the pupil works on the instructions of his teacher. He can rarely be left to his own initiative when dealing with problems which arise, and, if he does gain a proof, it is obtained in a wasteful manner.

Some writers assert that the direct method of verification has all the advantages of the heuristic method, as it attains its aims more easily and efficiently. This claim is not substantiated, however, and good teachers always include in their courses a number of problems embodying the spirit of the heuristic method.

Summary of conclusions.—Thus, it is best to carry out a modified form of the heuristic method with pupils aged 11 to 16. Teachers should give the minimum amount of help in response to the pupils' inquiries, and should only resort to ordinary teaching methods when it is realized that to keep strictly to the heuristic method is inadvisable. Information should be readily supplied if it is seen that a research problem is becoming uninteresting, or when the pupil has not sufficient knowledge to continue the work.

Junior pupils often derive benefit from pursuing heuristic methods in early lessons. Later, quicker teaching methods should be used. Much of the work can be built up on problems, but, with the approach of external examinations, practical work may be curtailed so that more time may be devoted to systematic and theoretical Chemistry. The wording of verbal or written instructions should be such that the results are withheld. Definite and direct instruction is, however, essential under present conditions of Chemistry-teaching in the majority of schools.

must always be kept in mind, and the relative advantages of each kind of apparatus must be demonstrated. Many experiments are beyond the scope of even the most enthusiastic pupil, and if such experiments were attempted, the results would be worthless from an educational point of view. Side reactions, or an apparent failure, might attract and hold his attention; he might then become absorbed in complex details and lose sight of the main problem.

Other experiments are too dangerous to be carried out individually. Juniors use inflammable liquids too carelessly. They should not carry out experiments with sodium, potassium or phosphorus if there is only one teacher to supervise a large class. Pupils do not sufficiently realize the extreme danger of violent reactions such as the addition of concentrated sulphuric acid or yellow phosphorus to potassium chlorate.

A movable sheet of 'safety glass'¹ serves as a transparent protective screen for experiments which may be dangerous.

The pupils must be able to see the demonstration clearly. In a lecture-room with tiers of seats this is easy, but in the usual laboratory large-sized apparatus must be used and every opportunity taken to emphasize changes: for example, long pointers may be placed on balances. It is sometimes an advantage to have a large mirror placed on the wall behind the demonstrator at a suitable angle (approximately 45°) so that pupils may see the demonstrator's hands and his apparatus clearly in the mirror. Large movable mirrors in frames may be substituted. The demonstrator must have all the apparatus neatly arranged beforehand and make sure that none of it is placed between the class and the experiment.

An entirely incorrect conception of the ideals of Chemistry may result if the practical work does not definitely prove from the beginning that laboratory results are reliable. An individual experiment on the effect of heating copper in air and under impure sand may in each case give a black covering on the copper, so that the pupils doubt the facts of combustion. Such failures must never be allowed to happen, and, unless the individual experiment can be improved, the demonstration method should be substituted.

Demonstrations save time. The necessary apparatus can be arranged before the experiment begins, and the time spent by pupils

¹ Manufactured and sold under trade names such as 'Triplex'.

in fixing up apparatus and tidying up the bench is thus saved. Material is also saved, as a large number of pupils in a class need many times the amount of chemicals required by the teacher in his demonstration. Further, the pupil obtains much benefit from important demonstrations carried out on a large scale. Such experiments, usually omitted from the course as individual work, are: the lead-chamber and contact processes for the manufacture of sulphuric acid; the electrolysis of concentrated hydrochloric acid (see Figure 34); the passage of purified air over heated copper; the condensation of the water obtained by the burning of dry hydrogen at a jet; the analysis of nitric acid; the oxidation of ammonia; the preparation of carbon monoxide from carbon dioxide and carbon; the Solvay process for the manufacture of sodium carbonate.

The procedure used during a demonstration varies with the ideas of the teacher and the conditions of the laboratory. In all schools, however, the teacher occasionally finds it necessary to stop individual work and to gather the pupils round the demonstration bench for instruction. Occasionally a class experiment is done badly. The laboratory instructions may be at fault, or the chemicals may differ from previous samples. The teacher should immediately repeat the experiment so that the proper result is obtained and the reason for the pupils' variable results is explained. If blotting-paper soaked in turpentine does not ignite in chlorine it can be warmed, or alternatively the surface area can be increased by the use of cotton-wool. When a pupil heats ammonium chloride, proves that ammonia is evolved, and states that the solid remaining is hydrochloric acid, he must be shown experimentally that his conclusion is incorrect. The results of a class experiment may sometimes be supplemented. Thus, for example, when hot concentrated sulphuric acid acts on copper in a test-tube, the resulting mixture can be cooled and carefully poured into a tall gas-jar of water to demonstrate the formation of blue copper sulphate in solution and of the insoluble copper sulphides.

Further, the Chemistry course for the first two years is best arranged as a series of problems and topics. Some lack of uniformity and coherence cannot be avoided. In consequence, the practical work of the pupil must be supplemented by demonstrations, talks, lectures and reading. The first three are usually given by the teacher,

each demonstration, and that he should be mentally satisfied at its conclusion.

Furthermore, the teacher must determine which of the two methods is the more suitable for specific experiments. For example, when he introduces volumetric analysis, he may find that very little is learnt, from sketches and descriptions only, of the correct methods of using pipettes and burettes. A demonstration, however, with large apparatus, plainly shows the pupils the technique necessary in order to obtain results of high accuracy.

The pupil ought then to practise the use of both burette and pipette, using water until he is sufficiently proficient in manipulative ability to use acids and alkalis. Pupils in pairs should check each other's results, and in practising the use of burettes the teacher should write down a definite volume, e.g. 36.6 c.c., and ask all pupils to run out water to that amount.

Deciding factors in the success of a demonstration are the experimental technique of the teacher and the rehearsal of the demonstration in private before the actual lesson. The young teacher must realize that a demonstration should not be attempted unless he is certain that it will succeed. If the demonstration fails it may have a serious effect on the attitude of pupils. Persistent failures not only influence class discipline, but the pupils may even lose confidence in the demonstrator himself. If the teacher is able to demonstrate effectively, if specially constructed large-scale apparatus is used, and particularly if a combined laboratory-lecture room is available, this method will, in general, be of great value to all pupils. Under these conditions, the teacher might seriously consider increasing the proportion of demonstrations.

Differing approaches for boys and girls

It is interesting to note that boys, on the whole, appear to prefer the individual method, and girls the demonstration method. One authoritative report states 'Boys are generally superior to girls in Chemistry' and further, 'Boys tend to excel in subjects where common sense counts for a great deal, and girls where style counts for not a little.' This is said to be noticeable in school practical work, for boys tend to be more efficient in manipulative skill and analytical work and, in consequence, prefer to carry out experiments individually. Girls

take more trouble in entering up their notes carefully and neatly, but are sometimes less efficient in individual experiments. However, many authorities believe that apparent differences are due to the influences of home, school and general environment. For example, boys often obtain higher marks than girls in Science examinations. This may be partly due to the fact that boys usually spend more time on Science and enjoy better facilities. It is said that boys seem to be more original and to give more reasoned statements. They are often more constructive, appreciate scientific principles, attempt to obtain their own results and conclusions, and are more satisfied by intellectual exercise. On the other hand, girls are often handicapped because Chemistry makes little appeal to their strong interests in domestic, human and emotional affairs. Some girls pay too much attention to unnecessary detail and isolated facts. They tend to lack self-assertion and scientific curiosity, but are more industrious and show greater ability at remembering facts.

It is suggested, therefore, that a larger proportion of demonstrations should be included in a Chemistry course for girls. Whether teaching boys or girls, however, the teacher should try to find out which of the two methods suits individual members of the class, and which is better for the experiment in question. It must not, of course, be assumed that boys have higher intelligence quotients than girls. The average is the same. There is, however, a wider range of ability among boys than girls, and it is now generally believed that there is less difference between the two than was formerly thought. Further, both require the same training in scientific method, as a help in solving problems in the home and everyday environment. It may also be true that most courses in Chemistry and General Science are essentially devised by men for boys rather than by women for girls.

Relative merits of the demonstration and individual methods

Demonstration work, however, links up with individual work in many ways. Demonstrators point out the correct use of apparatus. In individual experiments the pupil learns methods of manipulation and the scope and limitations of the apparatus. In the demonstration, the teacher shows how to control the variable conditions, how to avoid accidents and breakages and, in general, how to secure significant results. When experimenting the pupil should be encour-

aged to imitate the teacher's method. At first he will be handicapped by lack of experience, and it is only by constant practice that he will gain the necessary skill. After his own failures an intelligent pupil will realize his limitations and will in future observe the demonstration methods with more care.

The demonstration lesson is of necessity more definite in content than individual experiments. Thus, whilst it is instructive for all pupils, it is particularly helpful to the weaker pupils, who are thereby given opportunities for appreciating and learning the fundamental principles of Chemistry. Less scope, however, is offered in demonstrations for observing and recording unusual changes. In addition, physical tests, especially that of smell, must be done individually. It is, for example, almost impossible to describe in words the difference in smell between chlorine and hydrogen chloride. These gases must be tested personally by the pupils and, therefore, as it is inadvisable to spare the time with a large class to call up individuals to the demonstration bench, the pupils themselves must do the experiment. Small quantities of the gas, usually in solution in water, may be put into a test-tube and plugged lightly with cotton-wool. The test-tube can then be passed round the class.

In England, most teachers believe that the individual method is preferable, since the pupil may himself plan an investigation, carry out the necessary experiments to solve the problem, develop his manipulative skill, and psychologically satisfy his own demands for activity and for getting first-hand personal information. Also, external practical examinations make for its general retention. Nevertheless, educational research in America, described below, supports the contention that demonstration methods are at least as valuable as individual work in the laboratory, and it appears that this view is gradually gaining ground in Great Britain.

Conclusions on the teaching of practical Chemistry

In all his work, the young teacher must bear in mind the general principles and critical remarks made in this chapter.

It is impossible to place the pupil in the position of the pioneer who worked at a different period under different conditions, and with a different background of knowledge. A pupil becomes a research worker only in the sense that he obtains a body of knowledge from

many sources and that he discovers facts and formulates principles previously unknown to himself. Such sources may include demonstrations and lectures by teacher or pupils, individual experiments and personal observations, and a study of text-books and reference books. He has to advance a particular and definite step by his own experiments, which later must be comprehensively checked and fitted into the scheme of work and the collected knowledge of the class. His results may be part of a general investigation and may support and supplement the work of others. After the practical work, all the results are discussed, and when the summary and conclusions are obtained, the pupil should realize that his own work is a necessary and important part of the whole. On the basis of his own discovery (which, though controlled by the teacher, yet encourages initiative, skill, observation and reasoning), the pupil again widens his knowledge before repeating the whole process in future lessons. Thus he advances to wider knowledge and greater skill. The individual experiment becomes part of the scientific progress of the class. The pupil learns the need for critical checking, co-operation, full preparation and continual endeavour. He sees that theory and practice are inseparable. By visits to factories, by lectures and by frequent reference to authoritative sources, he learns to relate the artificial scientific life of the class to a wider field. Particular experiments—e.g. solubility curves, hardness of water, laws of constant composition and multiple proportions, volumetric analysis—lend themselves to group-work, since the results of all pupils may be used either to provide an average result or to build up graphs.

Review of research work done in the U.S.A.

The research work done on comparing the merits of individual and demonstration methods is mainly American, and should be more widely known. A summary and criticism of recent studies should be of benefit to the teacher.

The usual method of carrying out the comparative tests was to divide the pupils into two or more sections so that each pupil in one group could be compared with another pupil of approximately the same intelligence in another group. The classification was determined by mental tests and the pupil's grading in previous years' work. The instructions given, whether verbal or written, were iden-

tical for both demonstration and individual work. Thus, it was considered that all the conditions were constant except that the individual work was done by the pupil and the demonstration by the teacher.

One research worker kept separate accounts under the headings:— (a) what was done, (b) what happened, and (c) what the experiment proved. From retention tests he concluded that the individual method is 1 per cent. better in (c) and 6.5 per cent. better in (a); but 'what the experiment proves' is little understood whichever method is used.

In the first test the average time for a demonstration was thirty-one minutes, and in the second test twenty-three, whilst the individual method required forty-three and twenty-five minutes for the corresponding tests. Other conclusions were that different pupils react in different ways to the same type of tests, but that on the whole demonstrations were more effective than individual work.

It is estimated from observations that the cost of the apparatus and chemicals for the demonstrations to a class of thirty pupils was only 7 per cent. of that needed for individual methods. Further studies support the finding that demonstrations are better in training the pupil to tackle new problems and for 'what the experiment proved'. Individual methods are better for 'what was done' and 'what happened'. The combined method of giving a class one term of demonstrations followed by one term of individual laboratory work was found to be preferable to two terms of individual work. In immediate tests, better results were obtained by oral instructions in both demonstration and individual methods, whilst in delayed tests, written instructions were better for demonstrations but oral instructions were better for individual work. In general, little difference was shown between the two methods for delayed tests. In immediate tests, pupils obtained higher marks, in both demonstration and individual methods, when verbal rather than written instructions were given. In delayed tests, written instructions resulted in higher marks in individual work, and oral instructions in demonstrations. Other workers were dissatisfied with the earlier researches which tested the retention of facts. They determined which of the two methods was superior for developing laboratory skill and aptitude for solving problems. In both cases the individual laboratory method was inferior, except for solving very difficult problems. The nature of the

exercise, however, is an important factor in deciding which of the two methods is better.

It should be realized that there are many variable factors influencing the above results. These include the health of the pupil, the conditions of the surroundings, the nature of the material, and the doubt as to whether the two groups of pupils were of exactly the same mental calibre. Chemistry courses in America are less philosophical, and include more applications to everyday life, than the corresponding courses in Great Britain. Most of the researches tested the informative side of Chemistry; in fact, it is stated that 'we have no tests for scientific attitude, appreciation, manipulative skill and a scientific method of procedure', all of which a pupil should have developed. In general the researches compared the individual and demonstration methods alone, whilst in practice the two methods are often combined or modified. No exposition was given in the demonstration methods, and no explanation or demonstration was given to the pupil in the individual method. Thus the actual conditions of a school laboratory were not often reproduced.

The significant difference between the marks obtained in immediate and delayed tests indicates how much material is not retained. Chemistry is not alone in this respect, for in general 'about half of the subject-matter presented is forgotten after the first half hour, two-thirds in nine hours, three-quarters after six days and four-fifths after a month'. More satisfactory results would be obtained if less time were given to discussions on minor points, and more to emphasis of fundamental principles. Continual revision is necessary, and new problems should be introduced and solved by use of the recently acquired facts, so that earlier subject-matter is reinforced.

Final summary

The individual method is essential for discovery or re-discovery, when the result is still unknown to the pupil, while the demonstration method concentrates on emphasizing broad principles and on verifying the result of an experiment.

In an individual experiment the pupil has opportunities for viewing the changes as a close observer, and of taking his own readings. In a demonstration, certain features are pointed out to the class and only one or two pupils take the readings.

An individual experiment may be spoilt at one stage owing to lack of skill or knowledge, but in a demonstration the teacher prevents such failure by anticipating the difficulties. Alternatively, the teacher can show definitely how one unexpected factor adversely influences the result.

Although the majority of the experiments should be individual, the general usefulness of demonstrations must be stressed, for they are effective and economical in supplying knowledge, and they are particularly valuable in co-ordinating a series of facts, or in repeating a well-known historical experiment, and time must be allowed for their inclusion.

Finally, it seems quite certain that each of the methods under discussion has its own specific purpose and that neither can be omitted.

CHAPTER VII

The Treatment of Quantitative Work

Historical introduction

In the alchemical period little notice seems to have been taken of the weights of substances taking part in chemical reactions, and this attitude did not change during the years in which the phlogiston theory was in existence. Jean Rey, in 1630, published his work 'On an Enquiry into the Cause wherefore Tin and Lead Increase in Weight on Calcination'.¹ In 1673 the main facts of this research were confirmed by Robert Boyle, who incorrectly attributed the increase to the absorption of igneous particles, but the work aroused little interest. In consequence Joseph Black receives most of the credit for introducing the balance into chemical experiments. His work, published in 1755, gave direct evidence of the efficiency of quantitative methods. A little later Lavoisier's important investigations showed that the quantitative aspect of chemical reactions could no longer be neglected.

Errors in classical experiments.—It is of great interest to calculate the degree of accuracy obtained in the quantitative experiments used in the discovery of the fundamental laws of Chemistry.

Students might read the original records of early chemists and calculate the errors in their results. It is not surprising that the most expert manipulators could not secure greater uniformity, or more reliability, in their results, as it was often necessary for these men to design and construct their own apparatus and purify their own reagents.

The law of multiple proportions was suggested by Proust, in 1805, from his results on the analysis of the sulphides of iron. His experimental errors varied from 0.5 to 20 per cent. Dalton first enunciated his law from results which show errors up to 14 per cent. Black's outstanding work gave an error of 1.6 per cent., while Lavoisier's results on heating mercuric oxide gave a 1 per cent.

¹ No. XI, *Alembic Club Reprints*.

error, and yet these were the bases of the law of conservation of mass.

Cavendish's experiments in 1784 are of great importance for illustrative purposes. They show students how a great chemist refrains from making definite conclusions when inadequate knowledge of a reaction is available. Cavendish passed electric sparks through a mixture of air and oxygen, and after absorbing the excess oxygen by means of 'liver of sulphur' (i.e. sulphur dissolved in calcium hydroxide) he wrote:

'After which only a small bubble of air remained unabsorbed which certainly was not more than 1/120 of the bulk of the "phlogisticated air" [nitrogen] let up into the tube; so that if there is any part of the "phlogisticated air" [nitrogen] of our atmosphere which differs from the rest, and cannot be reduced to "nitrous acid" [nitric acid], we may safely conclude that it is not more than 1/120 part of the whole.' This cautious statement was proved to be correct in 1895, when Lord Rayleigh and Sir W. Ramsey showed that 0.93 per cent. of the air was composed of inert gases, the chief one being argon.

In scientific work the standard of accuracy has been much improved, of course, and it continues to rise. In contrast to the work just mentioned, it may be pointed out that a modern quartz-fibre balance is capable of weighing quickly and accurately to 0.000001 g. Very small weights can be determined in quantitative analysis, and the weight of the *sample* used in the micro-chemical method is often as small as 1 milligram.¹ As little as 0.000001 g. of an element may be detected in a drop of liquid by suitable qualitative methods. Indirect methods often give highly accurate results: e.g. the error is less than 1 in 10,000 in the determination of an atomic weight by means of the mass spectrograph.

Introducing quantitative Chemistry

At quite an early stage, and even before a balance is used, young

1 Various authors suggest different scales, but an approximate guide to the size of <i>sample</i> used in methods of quantitative analysis is as follows:—	
Ordinary method (macro-chemical).	100 to 500 mg.
Semi-micro-chemical	10 to 20 mg.
Micro-chemical	1 mg.
Ultra-micro-chemical	0.001 mg.
Sub-micro-chemical	0.00001 to 0.000001 mg.

pupils may be introduced to the idea of quantitative work. Examples are:—

(a) Solubility experiments. Powdered substances—e.g. Epsom salts, copper sulphate, sulphur, common salt, Glauber's salt and glass—are measured in a very small hole in a flat piece of wood or on a small circle marked on paper, and added to a known volume of water with its level marked by gummed paper on the outside of a test-tube. One measure is put into the water and the whole is shaken. Sufficient measures are added until the solution is saturated and a rough idea of solubility is thus obtained by comparing the number of measures dissolving.

If, as with sulphur, none appears to dissolve, the filtrate may be evaporated to dryness to see if there is any solid residue.

(b) The hardness of tap-, pond-, sea-, rain- and river-waters may be compared by adding soap-flakes (approximately the same size) to a medicine bottle containing 20 c.c. of each type of water and comparing the hardness by finding the number of flakes which must be added to give permanent lather, on shaking, after corking the bottle.

(c) Measuring the volume of hydrogen evolved from a known length of magnesium ribbon. A coil of magnesium ribbon is weighed by the teacher and its total length measured. Strips of magnesium can then be measured to represent a certain weight of the metal. For example: 8.54 g. of magnesium ribbon are found to measure 15.5 metres. What length will supply 100 c.c. of hydrogen at S.T.P.? 2 g., i.e. 22.4 litres, can be obtained from 24 g. of the metal.

$$\text{Now } 24 \text{ g. of the ribbon would measure } \frac{15.5 \times 24}{8.54} = 43.55 \text{ metres.}$$

Thus 22.4 litres of hydrogen could be obtained from 43.55 m. of the ribbon; ∴ at S.T.P., 100 c.c. of gas will be evolved from

$$\frac{43.55 \times 100}{22,400} = 0.194 \text{ m. or } 19.4 \text{ cm. of magnesium ribbon.}$$

(d) Counterpoised experiments. A long ruler pivoted on a nail and with a tray at each end is used as a balance. Sand is used as a counterpoise for the following demonstrations:—

- (i) Magnesium increases in weight on burning.
- (ii) The products of combustion of a candle weigh more than the original candle. The candle is placed in a tin can pierced at its base

with holes. Calcium oxide and sodium hydroxide are placed on a wire gauze above the burning candle. (In humid climates water vapour from the air is absorbed by the calcium oxide and sodium hydroxide, and counterpoised wire gauze containers must be placed on both sides of the ruler.)

Not unconnected with the quantitative aspects of Chemistry is the genuine interest some pupils take in production figures and in quantitative definitions. In dealing with production figures of metals, and different monopolies and controls, it is instructive to secure illustrative figures, and to note that, for example, Canada has a monopoly of cobalt, nickel and asbestos, Malaya and Indonesia of 88 per cent. tin, and the U.S.A. of 79 per cent. petroleum.

Hardness of water may prove to be a topic of interest, especially with regard to the local supply, and pupils may ask questions about its measurement. Different countries use different methods. In England it is measured in 'degrees', one degree of hardness meaning that one part of calcium carbonate (or its equivalent in other substances) is contained in 100,000 parts of water. The following terms are employed:—

Very soft:	under 5° of hardness
Moderately soft:	$5-10^{\circ}$
Slightly hard:	$10-15^{\circ}$
Moderately hard:	$15-20^{\circ}$
Hard:	$20-30^{\circ}$
Very hard:	more than 30°

In the U.S.A. the hardness is defined as the number of milligrams of calcium carbonate, or its equivalent, in one litre of water: i.e. the number of parts per million by weight. The teacher may be asked about the wastage of soap. The use of 1,000 gallons of water of 30° hardness involves a loss of 26 lb. of ordinary bar-soap (which contains 63 per cent. of pure soap). To obtain such figures is a good exercise in chemical calculation.

Facts such as the following supply precise information and stimulate valuable discussion:—

(a) In one hour a man breathes about 20 cu. ft. of air, producing, at rest, about 0.6 cu. ft. of carbon dioxide, and at least three times as much when doing hard muscular work.

(b) The oceans hold in solution between 18 and 27 times as much carbon dioxide as the atmosphere.

(c) One square mile of good garden soil gives off approximately 4,000 tons of carbon dioxide during the summer owing to the breathing of living creatures in the soil and owing to the decay of organic material.

(d) A single cow may drink as much as 10 gallons of water in one draught on a hot day and a total of 40 to 50 gallons during the day.

Fortunately many Chemistry courses in schools are preceded by meticulous instruction on the handling of balances. This means that when the pupil begins his experiments on verifying the law of constant composition, or the change in weight of metals which have been heated in air, the idea of weighing is no longer an abstract one. He has some skill in the use of a balance and is always anticipating the change in weight during the course of a reaction.

It is essential that the few results which the pupil obtains for himself in quantitative work should be sufficiently accurate for him to rely on their value. Many experiments which might theoretically be done in the laboratory on reacting substances must be rejected because they do not yield the same results when repeated by different pupils. The teacher must avoid the situation where, as one writer has put it, 'in too many cases gravimetric research with beginners is a guessing competition, the master being in possession of the answer'.

If inaccurate quantitative results are obtained in the school laboratory, it is advisable to discuss the reasons for the errors, and if possible the pupils should account for the differences. Much valuable training is gained if pupils suggest that the variation of their results from the theoretical one is due to such causes as absorbed moisture, an incomplete reaction, or the presence of a certain impurity. Pupils should be encouraged to find out when an experiment is complete, and to devise 'control' experiments for comparison.

There is much to be gained by performing some experiments, such as the determination of equivalent weights, by more than one method. But quantitative work which takes a long time, or which is merely repetition, should be replaced by simpler descriptive experiments not involving measurements but requiring independent thinking.

Quantitative experiments

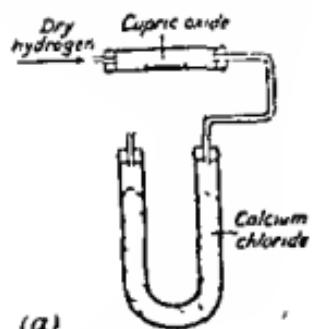
Simple experiments for juniors.—Bear in mind the previous considerations, there should be little difficulty in selecting the most suitable quantitative experiments for the junior years. The number and type should vary with the apparatus available and with the syllabus in use. Individual experiments ought to include the following:—

- (a) The measurement of the volume of gas evolved in a chemical change (use of aspirator or simple form of Hempel's burette (Figure 12)); to find (i) the percentage of carbon dioxide in a sample of calcium carbonate; (ii) the equivalent weights of magnesium or zinc by displacement of hydrogen from hydrochloric acid.
- (b) The determination of equivalents by:—burning magnesium in air; the oxidation of copper with concentrated nitric acid; the displacement of copper by zinc from copper sulphate solution.
- (c) The separation of a soluble from an insoluble substance (using water, and possibly another liquid, as solvent).
- (d) Gas analyses (composition of air, hydrogen chloride, etc.).
- (e) Crucible experiments (loss of water of crystallization, equivalent, use of muffle furnace).
- (f) The verification of the laws of constant composition, multiple proportions, conservation of mass.
- (g) The plotting of a solubility curve (use of a thermometer).
- (h) The reduction of an oxide (combustion tube for (b) or (f))—see Figure 23.
- (i) Measuring the hardness of water.

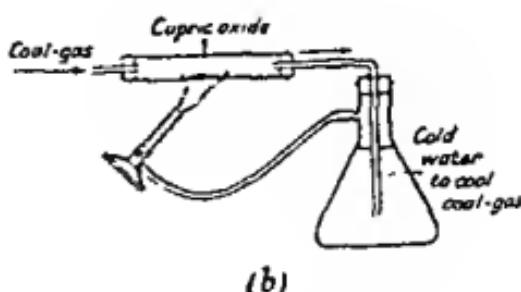
More advanced quantitative work.—If any advanced students are unfamiliar with the above quantitative experiments, they should perform them first.

1. *Volumetric analysis.*—In addition to volumetric analysis with acids and alkalis, potassium permanganate, silver nitrate and iodine, more advanced students might use potassium dichromate, potassium persulphate and potassium iodate. Suitable experiments in volumetric analysis, in addition to the preparation and standardization of solutions (usually N/10), include:—

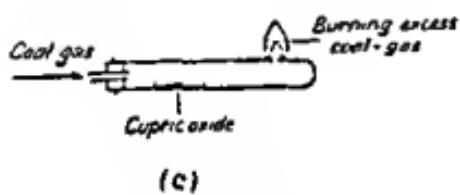
- (a) *Acids and alkalis*—strengths of concentrated acids; the equivalent of an organic acid; the percentage of ammonia in ammonium



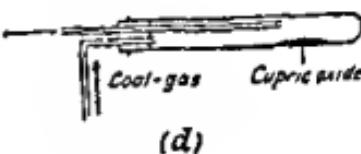
(a)



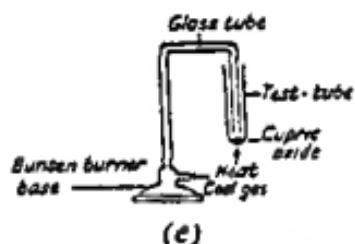
(b)



(c)



(d)



(e)

FIGURE 23.—The reduction of oxides by hydrogen or coal-gas:

(a), (b), (c), and (d) Various types of apparatus for quantitative experiments
 (e) A simple apparatus for the qualitative experiment

In the case of (a), (c), and (d) the whole apparatus is weighed before and after reduction. In (b) only the boat and its contents are weighed

chloride; the number of molecules of water of crystallization in washing soda; the purity of chalk or limestone; equivalents of insoluble oxides and carbonates, and of magnesium; a mixture of sodium carbonate and potassium carboonate; hardness of water; purity of borax.

(b) Potassium permanganate—the equivalent of oxalic acid; the purity of ferrous sulphate; the strength of hydrogen peroxide; the percentage of iron in a ferric salt; the purity of manganese dioxide; estimations of nitrite, chlorate and calcium in compounds.

(c) Silver nitrate—the concentration of hydrochloric acid or

sodium chloride solution; the purity of common salt; the percentage of silver in an alloy; a mixture of two soluble chlorides; estimations of chlorate and thiocyanate.

(d) *Iodine*—the strength of sodium thiosulphate; the percentage of copper in copper sulphate; the purity of bleaching-powder; estimations of reducing agents (stannous chloride, sulphur dioxide, hydrogen sulphide, arsenious oxide), and of oxidizing agents (hydrogen peroxide, potassium permanganate and dichromate, halogens).

(e) *Potassium dichromate*—similar to potassium permanganate but used in the presence of hydrochloric acid.

2. *Gravimetric analysis*.—Suitable exercises including problems on the number of molecules of water of crystallization in hydrates; the precipitation of the metallic ions:—barium, lead, copper, iron and magnesium, and of the sulphate ion.

3. *Other experiments*.—In addition to the quantitative problems in volumetric analysis, it is assumed that further problems in Physical Chemistry will include partition coefficient, chemical equilibrium, elevation of boiling-point, depression of freezing-point, heats of neutralization, electrical conductivity, and equivalent and molecular weights.

As stated elsewhere, it is essential that students should gain experience in the use of the different types of apparatus available. Titration experiments with standard solutions of silver nitrate and potassium permanganate may be done by more advanced students, and quantitative problems may be set as variations to the more usual work. A pupil may, for example, be asked to determine the percentage of carbon dioxide evolved from a known weight of sodium bicarbonate, on treatment with an acid, before and after heating.

The percentage volumetric composition of gases, such as carbon dioxide, sulphur dioxide, hydrogen sulphide, hydrogen chloride and the oxides of nitrogen, can be determined, by synthesis and analysis, with reasonable accuracy. For example, the fact that carbon dioxide contains its own volume of oxygen can be shown by using a large resistance-glass boiling-tube containing charcoal. The test-tube is fitted with a rubber bung and two pieces of glass tubing, and is filled with oxygen by displacement of the air. One tube is closed and the other is connected to a large funnel placed mouth downwards in a

large beaker of water saturated with carbon dioxide. The water is drawn up to a mark in the glass tubing. The large funnel (retort or wide U-tube) is necessary because of the expansion of the oxygen when the charcoal is being heated. The water is saturated with carbon dioxide by dissolving a little sodium carbonate in water and neutralizing this with dilute acid.

Further training regarding chemical reactions from a quantitative aspect is given by suitable teaching methods. Pupils should be taught to estimate the volume of test-tubes and other vessels, so that the laboratory instructions may readily incorporate the approximate weights and volumes of the reactants required; and they should secure also a clear conception of the need for using exact quantities in reactions, if the amounts are stated. Thus, '15 c.c.' is much preferable to 'two-thirds the length of a 5-in. test-tube'—even if the two are synonymous.

Lastly, training in small-scale methods should be given. These methods (see p. 158) depend on the fact that substances react equally as well in fractions of a cubic centimetre or gram as in litres or kilograms. Thus they help to stress the need for economy, and to emphasize the definiteness of a reaction and the constancy of the proportions of reacting substances.

The magnitude of errors.—The subject of the size of errors is one that the Chemistry teacher should introduce whenever possible. The treatment of any problem should, however, be within the understanding of the particular class and should only be introduced after the practical work has been done individually by the pupils. The mathematical aspect can be discussed after the object of the problem has been clearly grasped, but this must be well within the understanding of each pupil. The question of the relative value of errors is often omitted from school mathematics lessons. It is so important, however, that, whenever a series of results is handed in by the pupils, the teacher should make some reference emphasizing the aspect of relative errors.

Primarily, it must be realized that the result of a quantitative experiment varies. There is no absolute standard of accuracy, but the more expert the manipulator, the greater is the tendency for the results to approach the ideal. Methods of correcting errors by

'control' or 'blank' experiments, and by graphical methods, might be carried out by senior students.

Further, it should be recognized that any reading varies from time to time, even with accurately graduated instruments and careful observation. It is wrong to define an error as a deviation from the 'true result', for this implies perfection in the experiment and its results. Thus the 'true' or theoretical result of a chemical change is often based on calculations from atomic weights. These values have been determined practically, and therefore contain errors—minor ones it is true, but nevertheless errors.

It is well for the pupil to realize that chemical 'constants', which have been determined experimentally, are the best representative values of many observations. Senior students might also read with advantage about the precautions taken in the accurate determination of atomic weights.

Errors in quantitative work

Errors can be placed under various headings for convenience of class discussion. The following are some divisions: chemical, physical and personal errors; unavoidable and avoidable errors; constant and variable errors. The last classification will be referred to here, although all are arbitrary.

Constant errors.—The constant error made in an experiment by a given method cannot be avoided by repetition. It may be due to gross faults such as: inaccurate calibration in volumetric apparatus; faulty standardization of solutions; impurities in the stock solution used; incorrect methods. (Thus the determination of the equivalent of copper, by conversion to nitrate and beating, gives consistently high results owing to loss of copper.) Personal errors may sometimes be referred to as constant errors, for even after years of training some experimenters always read the level of a liquid in a graduated vessel inaccurately, giving it too high or too low a value. In titrations, the reading of the exact colour change is rarely recorded, as the tendency is to anticipate the change. Experienced observers at Greenwich make similar errors in recording the time of a star's transit. (The assumed instant of its actual occurrence varies from one-thousandth to

one-third of a second, and this error is almost constant.) In such cases, experts might obtain exactly reproducible results by making always the same error in one direction rather than another. Such constant errors cannot be detected or eliminated by repetitions of the same method, but alternative methods, different observers, or other instruments and materials might reveal them.

Variable errors.—Variable errors are often due to carelessness in mechanical operations such as: weighing and the reading of graduated scales; loss in weight owing to transfer of a substance to another vessel; parallax errors in the reading of graduated vessels; mistakes in recording or calculating results. It is one of the aims of Science to prevent occurrences of this kind. The checking of one pupil's results by another pupil and the repetition of experiments by different methods, if time permits, are occasionally resorted to. In practice, many pupils are given insufficient time in the early years to become thoroughly proficient, except in very simple quantitative experiments. In later years the personal error may become comparatively small.

The magnitude of personal errors, due to limitations of the observer's senses and apparatus, varies with the physical and mental conditions of different recorders and with the complexity of the experiment. Even the same experimenter works with greater care and accuracy at some times than at others. These personal errors can be minimized by much practice, by the intelligent handling of apparatus, and by creating special conditions before the errors become constant. It is doubtful if the average pupil can attain such an ideal, but his training should be towards that end.

Other variable errors may be due to the difficulty of the experiment, or to faulty apparatus. Such instances can be most interesting and instructive when tackled by the advanced students; but the ideal experiment for most juniors is a straightforward reaction requiring a simple technique. Even in simple experiments, errors are incurred by careless handling of materials. Some errors are difficult to avoid, especially in taking indirect measurements, where several observations introduce their own particular error. Examples are found in: the determination of the solubility of a solid at different temperatures, the rate of a reaction, or any experiment in which portions of

a solution are periodically removed from a stock solution. Again, in quantitative work it is assumed that the so-called compound formed has a fixed composition: the side products must not interfere with the main reaction. But this may not be the case, and in consequence, some experiments cannot be repeated so that consistent results are obtained. For example, varying weights of copper nitrate and nitrogen peroxide may be formed by the action of a fixed weight of concentrated nitric acid on excess of copper.

It may happen that an experiment which appears incorrect is merely incomplete. To verify this, pupils should be encouraged to retain their specimens in order that tests may be carried out. It is a useful exercise to test for the completeness of quantitative reactions of the following type: reduction of cupric oxide with hydrogen (to constant weight) (Figure 23); washing the precipitate of silver chloride and adding silver nitrate solution to the filtrate (to ensure complete precipitation of the soluble chloride); reduction of ferric chloride (test for ferric salts); and various volumetric analyses.

The quantitative work in the first four years must be of the simplest, and full instructions must be supplied. Numerous errors in manipulation occur through carelessness or lack of appreciation of the size of errors. It is usually necessary, in practice, to inform pupils repeatedly of the errors incurred by decrepitation, 'creeping', insufficient drying, incomplete precipitation, and the careless reading of graduated instruments. These errors can only be minimized by individual laboratory experience and training. In schools, they are of more importance than systematic errors, which are usually too small to affect the accuracy of junior quantitative work.

The treatment of errors.—The treatment of errors has the advantage of training the reasoning powers as well as of encouraging the acquisition of facts. Inaccuracies in gravimetric work must not be ignored, as a discussion of the reasons for their occurrence may do more good than a correct result mechanically obtained.

It should be emphasized that the result is not as important as the correct and conscientious performance of the experiment, and 'faking' of results is thus discouraged.

When a class experiment is completed, all the individual results

should be put on the blackboard. For instance, one set of results for the percentage of carbon dioxide in a sample of calcite was:

43.8	43.2	44.2	(39.1)	42.9
44.0	43.3	42.9	43.7	43.6
44.3	43.8	44.6	(41.1)	43.5

43.1

Mean result = 43.6 per cent.

Pupils can usually see which results are most likely to be incorrect. The figures in brackets, for example, were considered to be valueless, as they were widely divergent from the other values. The mean result was compared with the theoretical result obtained by calculation from the atomic weights. The apparatus used was a small test-tube, containing the concentrated hydrochloric acid, and a boiling-tube fitted with a cork and drying-tube, containing 1 g. of the calcite. Suggestions as to likely sources of error were made by pupils. These included the possibility of carbon dioxide remaining in the boiling-tube or dissolving in the acid; inaccuracy in the several weighings; the existence of impurities in the calcite; and loss of liquid. Finally, methods were suggested for remedying such faults.

The correction of errors is of great educational importance, for it develops in the pupil a sense of proportion and relative value seldom introduced by other subjects in the school curriculum. In an experiment, only original and thoughtful pupils are on the look-out for, and are prepared to consider, the relative importance of likely errors. It is important, however, that all pupils should be given opportunities to receive some training in appreciating the reasons for the differences between the results obtained in the laboratory and the theoretical values.

Calculating the value of errors. — In practical work the importance of accurate weighing must be emphasized, and it must be shown by calculation that small mistakes which occur in the course of an experiment may produce a serious effect on the final result. This is especially true when small amounts of materials are used, or when the change in weight is comparatively small.

Thus the results given with the experiment on the percentage of carbon dioxide in calcium carbonate are limited by the accuracy of the balance. A school balance rarely records differences of less than

0.005 g. With such weighing a possible error of 0.0025 g. was incurred, equivalent to a percentage error of 0.25. In addition, three different weighings were necessary, so that the total error might rise to 0.75 per cent., although it is unlikely that such would occur.

In the determination of equivalent weights by measuring the volume of hydrogen evolved, the use of small quantities of metals is necessary, and consequently large errors may occur. For example, with 0.1 g. of aluminium a percentage error as large as 2.5 might be brought into the experiment by weighing. In an experiment determining the weight of oxygen liberated from mercuric oxide, the fact that the theoretical loss due to oxygen is only 7.4 per cent. is a serious defect in the method. The remedy is not always easy. The percentage error could be reduced by using large amounts of substances, but, as both cost and length of time to perform the experiment have to be considered, this is not always convenient.

Each experiment should be considered separately, and appropriate action for reducing any errors should be taken. For example, the heating of large weights of mercuric oxide in determining the loss in weight of the combined oxygen would require the use of a glass condenser, or glass wool in the mouth of the test-tube, to prevent the loss of mercury vapour. If a large volume of oxygen is measured and its weight calculated from its density, the error can be reduced to a small value.

After the junior stage of Chemistry has been passed, pupils are expected to consider both the precautions to be taken to secure reasonable results and the degree of accuracy to which these lead. They should attend to relevant details and learn to work out results as accurately as the conditions of the experiment permit. Time should not be spent in attempting to avoid errors which are insignificant. Pupils must realize that accuracy is not of the same value in every measurement. Appreciable errors should be avoided, but it is unnecessary to take precautions to prevent very slight errors occurring. Pupils should be taught to realize that it is a waste of time to use an accurate balance for weighing materials used, for example, for standard solutions in volumetric analysis, and then to use these solutions in a badly calibrated pipette or burette. The student should be clear about the nature of the errors at each stage, so that all

measurements are of the same degree of accuracy. In other words, excessive accuracy at one stage of a series of operations is useless if the other stages are less accurate. It is absolutely wrong to calculate a result to a degree of accuracy which bears no relation to the results obtained. (A teacher should take every opportunity of emphasizing the fact that 'the number of significant figures' is of primary importance in *all* calculations.) As an example, in weighing 5 g. of a solid to the nearest 0.005 g. the possible error is 0.0025 g.

$$\therefore \text{percentage error is } \frac{0.0025 \times 100}{5} = 0.05$$

With a more delicate balance the error can, of course, be reduced.

If 5 g. are dissolved and made up to 100 c.c. with water, and if a burette is used which reads to the nearest 0.025 c.c., it might be imagined that the error would be half this value. Actually a burette delivers about twenty drops per cubic centimetre, and thus the greatest accuracy is within half a drop, or 0.025 c.c.

If 20 c.c. of this solution is used the percentage error might be

$$\frac{0.025 \times 100}{20} = 0.125$$

With 5 c.c. of this solution the percentage error is increased to 0.5 per cent.

The figures given are sufficiently accurate to show that weighing is usually more precise than volumetric measurement, especially when small volumes are used in titrations, and that small volumes incur a large percentage error.

Another common tendency which must be discouraged is to express averages of a number of measurements beyond the degree of accuracy they justify. Thus if 0.300 g. of potassium chlorate loses 0.115 g. of oxygen, it is wrong for the pupil to express the loss in weight on 1 g. as 0.3833 g. He should be told that the accuracy of his calculation depends on the accuracy of the weighing. As previously mentioned, this is usually to the nearest 0.005 g. with an average school balance. The 0.115 g. represents a value between 0.1155 and 0.1145 g. Thus the loss on 1 g. should be expressed as 0.383 g., and the other figure given is meaningless.

Summary

To sum up, it might be stated that, although comparatively few direct quantitative experiments are advocated in the junior course, those selected should be reliable. It must also be pointed out that much qualitative work has a quantitative basis. Indeed, this aspect should be continually brought to the notice of beginners.

In preparing different salts in the first year's course, acids are neutralized by a metal, metallic oxide, carbonate and hydroxide. In the first two cases the pupils know that the acid is neutralized when excess of metal or metallic oxide is present. In the third, neutralization is reached when effervescence ceases, and in the last (using a soluble hydroxide) when an indicator shows a special colour. Thus the idea that exact amounts are required is stressed. When measuring instruments such as pipettes and burettes are used all the class results can be referred to and discussed.

Later, when considering the differences between mixtures and compounds, pupils have other quantitative points of view brought to their notice in the synthesis of ferrous sulphide and its differences from a mixture of iron and sulphur. The analysis of air, the synthesis of water and the preparation of gases all supply information based on definite weights and volumes.

A young teacher may find it advisable to include experiments involving measurement of volume rather than weight. This suggestion should be considered if large classes have to be taught, or if the laboratories have few balances. The experiments on the measurement of volumes of hydrogen, carbon dioxide and oxygen evolved from reactions, the analysis and synthesis of gases, and volumetric analysis with acids and alkalis, make it unnecessary to perform many gravimetric experiments which include series of weighings. None the less, considerable practice in weighing is needed if reasonable speed and reliability are to be attained—skills often necessary for the passing of practical examinations.

Chemical arithmetic

A few chemical calculations have already been mentioned, and numerical errors in the results of quantitative experiments have been considered above. This raises the question of chemical arithmetic in general, and some brief comments are necessary.

Arithmetical examples should be introduced gradually, as opportunities arise, and they should fit naturally into the course. Pupils should be taught how to solve the problems by methods which involve clear reasoning. The use of atomic weights in calculations has to be learned at a fairly early stage. This is chosen as the subject for the series of questions given below, the approximate atomic weights of elements being employed.

(1) Calculate the molecular weights of (a) hydrochloric acid; (b) sulphuric acid.

(a) Atomic weights: H = 1; Cl = 35.5

$$\therefore \text{molecular weight of HCl} = 1 + 35.5 \\ = 36.5.$$

(b) Atomic weights: H = 1; S = 32; O = 16

$$\therefore \text{molecular weight of H}_2\text{SO}_4 = (2 \times 1) + 32 + (4 \times 16) \\ = 2 + 32 + 64 \\ = 98$$

(2) What is the simplest formula of a substance containing 29.1 per cent. of sodium, 40.5 per cent. of sulphur, and 30.4 per cent. of oxygen?

Atomic weights: Na = 23; S = 32; O = 16

\therefore the ratio of the number of atoms is:—

$$\begin{aligned} \text{Na : S : O} &= \frac{29.1}{23} : \frac{40.5}{32} : \frac{30.4}{16} \\ &= 1.27 : 1.27 : 1.9 \\ &= \frac{1.27}{1.27} : \frac{1.27}{1.27} : \frac{1.9}{1.27} \\ &= 1 : 1 : 1.5 \\ &= 2 : 2 : 3 \end{aligned}$$

i.e. the simplest formula is:— $\text{Na}_2\text{S}_2\text{O}_3$.

(3) How much iron could be obtained by complete reduction of 2 tons of haematite, Fe_2O_3 ? What weight would be obtained if the haematite were 95 per cent. pure?

Atomic weights: Fe = 56; O = 16



i.e. $(2 \times 56) + (3 \times 16)$ tons of haematite yield 2×56 tons of iron
or 112 + 48 " " " " " 112 " " "

or 160 tons of haematite yield 112 tons of iron

$$\therefore 2 \text{ " " } \frac{112 \times 2}{160} \text{ tons of iron}$$

$$= 1.4 \text{ tons of iron}$$

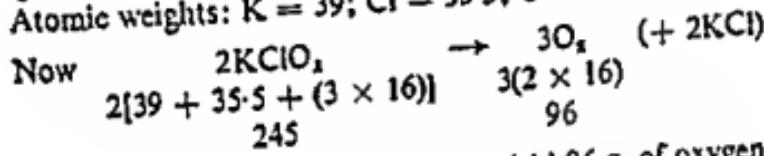
If the haematite were 95 per cent. pure, then 95 per cent. of this amount of iron would be produced:—95 per cent. of 1.4 tons

$$= \frac{95}{100} \times 1.4 \text{ tons}$$

$$= 1.33 \text{ tons.}$$

(4) What is the weight and the volume of oxygen, at S.T.P., that may be obtained by heating 50 g. of pure potassium chlorate?

Atomic weights: K = 39; Cl = 35.5; O = 16



i.e. 245 g. of potassium chlorate yield 96 g. of oxygen

$$\therefore 50 \text{ g. " " " } \frac{96 \times 50}{245} \text{ g.}$$

$$= 19.6 \text{ g. of oxygen}$$

The molecular weight in grams of oxygen occupies 22.4 litres at S.T.P.

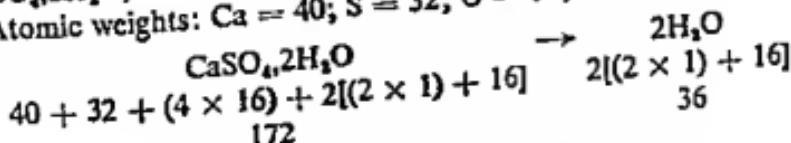
i.e. $2 \times 16 \text{ g. } = 32 \text{ grams of oxygen occupy } 22.4 \text{ litres at S.T.P.}$

$$\therefore 19.6 \text{ " " " } 32$$

$$= 13.7 \text{ litres at S.T.P.}$$

(5) What is the percentage loss of weight when gypsum, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$, is heated strongly?

Atomic weights: Ca = 40; S = 32; O = 16; H = 1



i.e. 172 g. of gypsum yield 36 g. of water

$$\therefore 100 \text{ g. of gypsum yield } \frac{36 \times 100}{172} \text{ g. of water}$$

$$= 20.9 \text{ g. of water}$$

i.e. Loss of weight = 20.9 per cent.

(6) What is the minimum weight of pure marble to yield 10 litres of carbon dioxide at S.T.P.?

Atomic weights: Ca = 40; C = 12; O = 16



$$40 + 12 + (3 \times 16) \quad 12 + (2 \times 16)$$

i.e. 100 g. of marble yield 44 g., or 22.4 litres of carbon dioxide at S.T.P.

\therefore 10 litres of carbon dioxide at S.T.P. are yielded by $\frac{100 \times 10}{22.4}$ g. of marble

$$= 44.6 \text{ g. of marble}$$

A series such as this, for each type of chemical calculation encountered, is very useful. It enables the pupil to get practice in the method of working recommended for the particular type; it helps him to understand the reasoning necessary at each step of the calculation; and it aids his memory for the facts and principles required in the solution of the problem.

CHAPTER VIII

Small-scale Apparatus and Experiments

Advantages of the small-scale approach

Senior pupils usually become reasonably proficient in carrying out tests by small-scale methods. The use of sensitive instruments, such as microscopes, necessitates accurate observation; the greater range of experiments widens the pupils' knowledge; and the novelty and neatness of the methods appeal to precise and careful pupils. It is not, of course, recommended that the usual methods should be replaced entirely by small-scale methods.

The relatively small amounts of material required for this special technique should be noted by teachers in schools. Large classes can carry out experiments individually at small cost. For example, in performing a test for a sulphate, 5 c.c. of a dilute solution of barium chloride are often added to the same volume of sodium sulphate solution. The test can be performed just as efficiently with one drop (0.05 c.c.) of each solution, equal to 1 per cent. of the chemicals previously used. A pupil appreciates the sensitivity of such tests when he finds that 0.2 g. of a solid dissolved in 10 c.c. of water suffices for many reactions of this type. This weight of solid means that only 0.001 g. need be used, and a tremendous saving in the cost of chemicals results. Substances such as potassium iodide, iodine and salts of mercury, silver and cadmium, which are too expensive for class use with larger apparatus, may be included, because only a trace of the substance is required with small-scale apparatus.

Dangerous large-scale experiments are advisably omitted in school work, because of the large numbers of pupils present in a laboratory and the inexperience of the experimenters. Such reactions are quite safe with small-scale methods, as later examples show. A further advantage is that when a solid is in solution it takes a few seconds only to extract several drops for testing purposes, and, what is quite as important, it takes no longer to wash and dry the apparatus for future experiments. Reactions occurring in thin films on pieces of glass or porcelain can be distinctly observed. The region of the

reaction is clearly defined, and complex colour changes or crystal formation can easily be viewed, especially with a lens or microscope. Crystallization of salts such as potassium nitrate, lead nitrate and ammonium chloride can be carried out by the usual neutralization experiments followed by concentration, or by adding reagents which supply a common ion.

Finally, a reaction may be quickly completed, because a large amount of one reagent can conveniently be added to the test solution. Thus, on dissolving copper in concentrated nitric acid and subsequently adding excess of ammonium hydroxide it is more effective to carry out the test on a slide, or on a piece of blotting-paper, than with several cubic centimetres in a test-tube. The excess acid is quickly neutralized in the small-scale (or micro-) method, and the merest trace of copper gives a blue coloration.

Apparatus and methods

The following descriptions give a useful indication of the application of small-scale methods with pupils aged 15 to 18.

It may be mentioned that 1-c.c. pipettes graduated in 0·01 c.c., 10-c.c. pipettes graduated in 0·1 c.c. and 10-c.c. burettes in 0·02 c.c. are on sale. If such instruments are not available, increased accuracy may be obtained, in reactions with sharp end-points, by using very dilute solutions such as N/100 silver nitrate and N/100 iodine. These examples give the pupil some idea of the possibilities of volumetric work.

Qualitative reactions are usually carried out with drops of liquids and solutions, small quantities of solids, and small volumes of gases, using special apparatus. The use of single drops gives excellent results and is typical of the small amount of substance that can be seen reacting. Reactions are usually carried out on watch-glasses, glass slides, or coloured tiles. Scrap glass may be bought cheaply, and cut into rectangles of convenient size (4 × 1½ in. and 4 × 4 in. are useful). If a precipitate cannot be seen distinctly, a suitable background is provided by the use of a coloured tile, or by placing a piece of coloured paper underneath the glass.

Solutions are stored in various kinds of bottles. Special reagent bottles may be bought, but medicine bottles fitted with bored corks carrying a glass tube drawn out to a point are cheaper. Small bottles

with screwed tops and dropping-pipettes are excellent for such reagents as silver nitrate and potassium iodide solutions; these bottles are used for packing certain pharmaceutical preparations.

Glass rods drawn out to a fine point, and fountain-pen fillers, are useful for handling small amounts of liquids. The usual method is to withdraw, with a piece of glass tubing, one drop of the solution to be tested, and to place it on a clean, dry glass slide (see Figure 35). A drop of the reagent is placed alongside it, and a clean glass rod is used to unite the two. The main reaction occurs at the zone of contact, but since each reagent is in excess on either side of this zone, unusual and instructive complications may result.

Conditions for some reactions may be varied by placing one drop of the reagent in the centre of the test solution. Careful observation enables the experimenter to decide whether the proportion or concentration of the reagent should be varied.

Such reductions in the quantities of the reacting substances necessitate modifications in the type of apparatus used. It must be the smallest apparatus that can be bought, or it must be specially designed. The course of most reactions may be followed by the unaided eye or with a pocket lens. Occasionally it may be advisable to use a microscope, or, for class purposes, a micro-projector.

Except for such special apparatus, most of the stock can be stored in a large box fitted with racks, slits and compartments to hold test-tubes, bulb-tubes, slides, rods, forceps, Bunsen burner and reagent bottles. Some slight modifications are necessary for such operations as small-scale filtrations and distillations. Strong wire may be bent into a convenient shape to support a small funnel and test-tube, and with the help of a cork cut in two the apparatus may also serve as a burette stand (see Figure 24). Alternatively, a combined test-tube rack and beehive shelf (Figure 15) can be improvised from copper foil, plastic or wood. Its size should be such that it fits on top of the beakers and is convenient for the standard glass tube and test-tube fittings. Many variations of the above apparatus may be devised. Small volumes of liquids can be distilled by means of apparatus such as that shown in Figure 25. A tube may be sealed into the side of a test-tube and this outlet joined to a length of glass tubing which is surrounded by a jacket of wider bore. Cold water may then be circulated through the jacket. An alternative apparatus is provided by bending a 4-inch

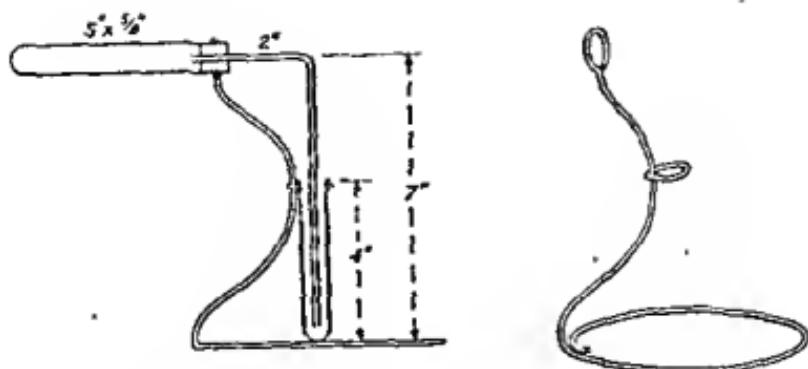


FIGURE 24.—A test-tube and funnel stand made from stout wire

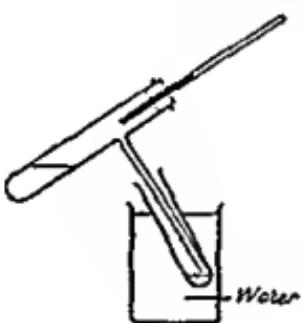


FIGURE 25.—Small-scale distillation

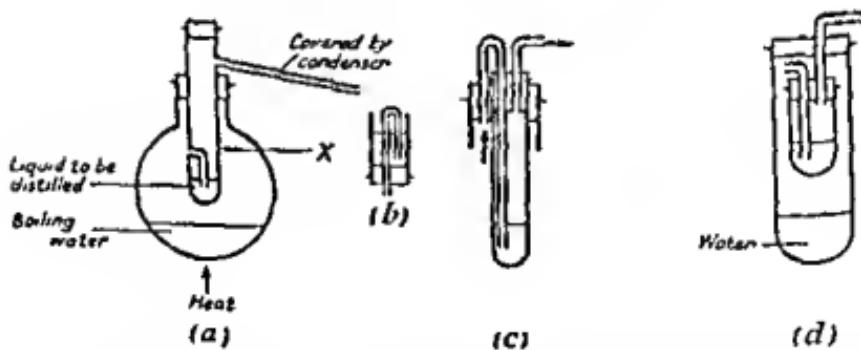


FIGURE 26.—Apparatus for distillation in steam (small-scale). (b) shows an alternative arrangement for *X*, using an inverted test-tube with side tube; (c) is a third variation, using a test-tube without a side tube; (d) gives another version of the apparatus

test-tube at an angle of 90 degrees, fitting it with a rubber bung and a piece of tubing, and surrounding with cold water a second test-tube joined to it. (Examples of apparatus for small-scale distillation in steam are shown in Figure 26.)

Experiments with gases

For the preparation and collection of gases, modification of the usual type of apparatus is especially useful. Experiments are often just as successful when small, instead of large, volumes of gases are prepared (see Figure 27), and the danger of a foul atmosphere in the school laboratory is minimized. Small test-tubes, 3 in. \times $\frac{1}{2}$ in. or 2 in. \times $\frac{1}{2}$ in., are most satisfactory for heating small quantities of mercuric oxide, potassium chlorate, or red lead. The final results are obtained quickly and, in the case at least of lead compounds, which combine with the glass, the cheap test-tube can be thrown away afterwards.

Small-scale methods similar to those previously outlined give efficient results when minute pieces of solid are placed in drops of liquids on a glass slide or watch-glass. The gas evolved is tested by suspending drops of different reagents on glass rods, loops of wire, glass slides and capillary tubes, or by impregnating strips of blotting-paper with the solutions. If very small volumes of gas are evolved, or if the tests are not very delicate, a more sensitive method is necessary, and a small piece of glass tubing is placed over the solid and the reacting drop. The gas is concentrated in this small cylinder, and the above drop-tests are carried out.

The teacher may prefer pupils to handle small-scale apparatus for preparing gases, rather than larger flasks, etc. (see Figure 27). Standard fittings for different-sized test-tubes are recommended. With a little thought, it is possible to prepare the common gases in sufficient amounts by using test-tubes and two or three bent pieces of glass tubing joined by rubber tubing.

It is suggested that each pupil should provide himself with fittings (3) similar to those shown in Figure 28. The glass tubing should be

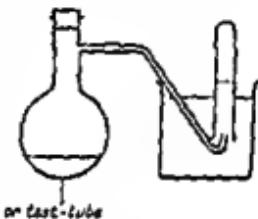


FIGURE 27. — The preparation and collection of a small volume of a gas

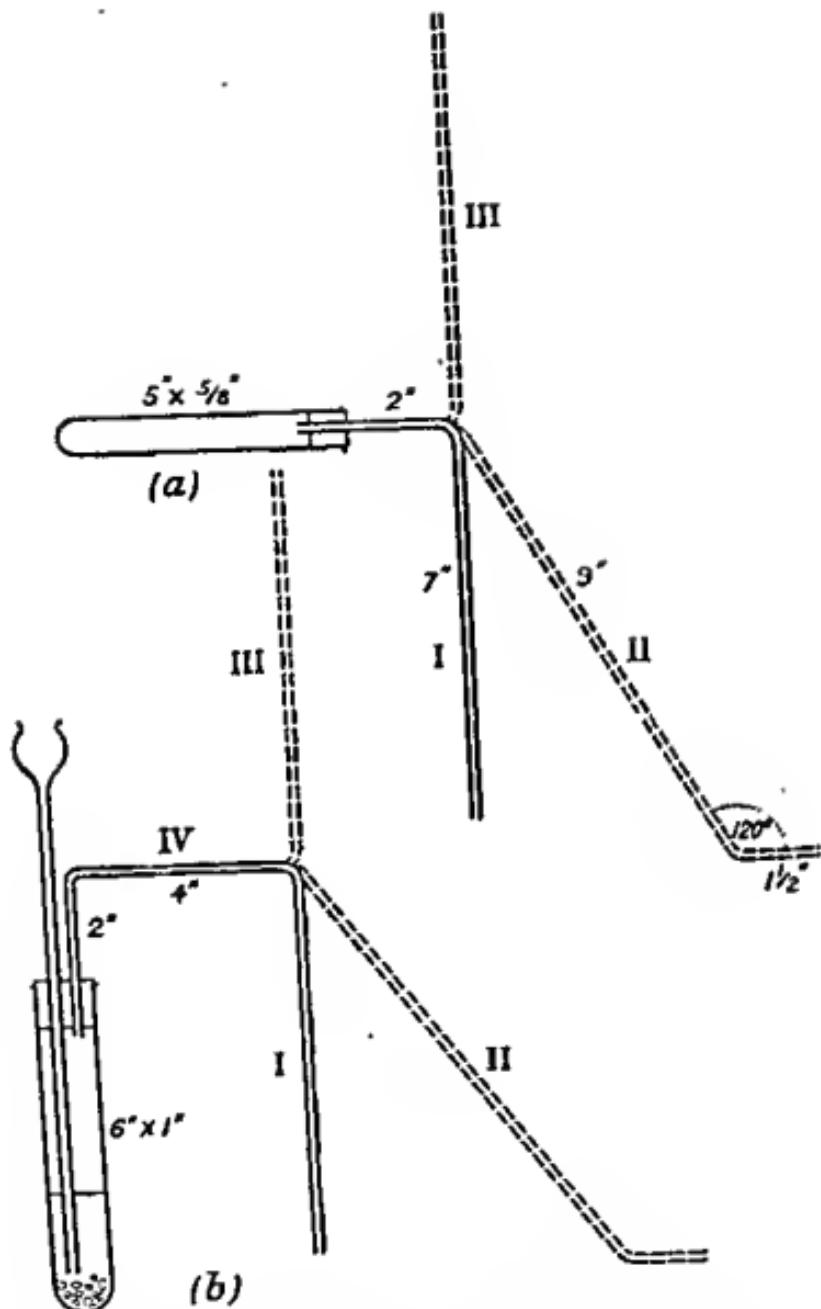


FIGURE 28.—The preparation of gases: unit small-scale apparatus

of a uniform bore so that the same rubber bung or cork and rubber tubing serve for different combinations. A $5 \times \frac{1}{4}$ in. test-tube is shown, but smaller ones may be used in cases where no effervescence occurs. Apparatus (a). I is most convenient for simple qualitative tests; the other arrangements are referred to in the notes below.

Collecting gases

(a) For gases denser than air, use the apparatus shown in diagrams (a). I or (b). I: e.g. carbon dioxide, nitrogen peroxide, hydrogen sulphide, chlorine, sulphur dioxide, nitrous oxide, and hydrochloric acid gas.

(b) For gases less dense than air, use the apparatus shown in diagrams (a). III or (b). III: e.g. hydrogen, ammonia, and methane.

(Note that the densities of gases such as carbon monoxide, nitric oxide, oxygen, nitrogen, and some of the above gases differ little from that of air.)

(c) For displacement of water, use (a). II or (b). II: e.g. with carbon monoxide, oxygen, nitrogen, hydrogen, nitric oxide. Other gases, such as hydrogen sulphide, chlorine and nitrous oxide, are slightly soluble, and may be collected over warm water, etc. Ammonia, hydrogen chloride, sulphur dioxide, and nitrogen peroxide are soluble in water.

Gases may be dried by using a suitable drying agent in a U-tube (see Figure 23 (a)) or a test-tube fitted up as a wash-bottle. Other modifications are sometimes necessary. The usual pneumatic troughs

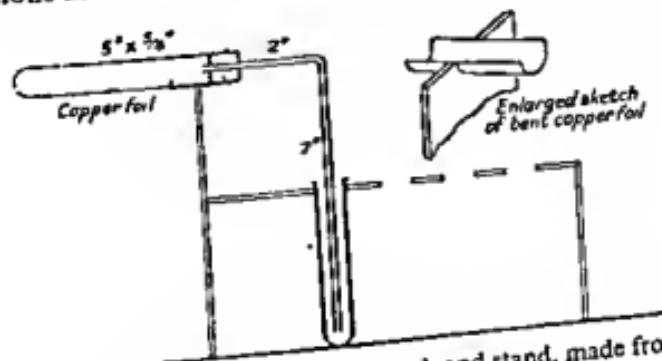


FIGURE 29.—A combined test-tube rack and stand, made from sheet metal

For- mula	Preparation	Appar- atus	Tests
O ₂	$2\text{KClO}_3 \xrightarrow[\text{MnO}_2]{\text{heat}} 2\text{KCl} + 3\text{O}_2$	(a).II	Rekindles glowing splint. (NO gives red NO ₂ .)
H ₂	$\text{Zn} + \text{H}_2\text{SO}_4 \xrightarrow{\text{dilute}} \text{H}_2 + \text{ZnSO}_4$	(b).III or (b).II	Slight explosion when first lit; pure gas burns giving water only.
N ₂	$\text{NH}_4\text{NO}_3 \xrightarrow{\text{heat}} \text{N}_2 + 2\text{H}_2\text{O}$ solution	(b).II	Negative tests.
CO ₂	$\text{CaCO}_3 + 2\text{HCl} = \text{CO}_2 + \text{CaCl}_2 + \text{H}_2\text{O}$	(b).I	Turns lime-water milky.
CO	$(\text{COOH})_2 \xrightarrow[\text{conc.}]{\text{heat H}_2\text{SO}_4} \text{CO}_2 + \text{H}_2\text{O} + \text{CO}$ Pass through NaOH	(b).II	Burns with blue flame, forming CO ₂ .
Cl ₂	$\text{MnO}_2 + 4\text{HCl} \xrightarrow[\text{conc.}]{\text{heat}} \text{MnCl}_2 + 2\text{H}_2\text{O} + \text{Cl}_2$	(b).I	Smell. Greenish yellow colour. Bleaches. Liberates I ₂ from KI.
HCl	$\text{NaCl} + \text{H}_2\text{SO}_4 \xrightarrow[\text{conc.}]{\text{heat}} \text{HCl} + \text{NaHSO}_4$	(b).I	Dense fumes with NH ₃ . White precipitate with AgNO ₃ solution.
SO ₂	$\text{Cu} + 2\text{H}_2\text{SO}_4 \xrightarrow[\text{conc.}]{\text{heat}} \text{SO}_2 + \text{CuSO}_4 + 2\text{H}_2\text{O}$ (spp'tox.)	(b).I	Smell. Drop of KMnO ₄ solution decolorized and product then gives white precipitate with BaCl ₂ .
H ₂ S	$\text{FeS} + 2\text{HCl} \rightarrow \text{H}_2\text{S} + \text{FeCl}_2$	(b).I or (b).II	Smell. Blackens lead acetate paper.
N ₂ O	$\text{NH}_4\text{NO}_3 \xrightarrow{\text{heat}} \text{N}_2\text{O} + 2\text{H}_2\text{O}$	(a).I or (a).II (hot water)	Rekindles glowing splint. Unaffected by alkaline pyrogallol.
NO	$3\text{Cu} + 8\text{HNO}_3 \xrightarrow[\text{moderately conc.}]{\text{no air}} 3\text{Cu}(\text{NO}_3)_2 + 2\text{NO} + 4\text{H}_2\text{O}$	(b).II	Exposure to air gives NO ₂ . Brown colour with FeSO ₄ solution.

NO.	As for NO, but with concentrated HNO_3 . $\text{Cu} + 4\text{HNO}_3 = 2\text{NO}_2 + \text{Cu}(\text{NO}_3)_2 + 2\text{H}_2\text{O}$	(b).I	Reddish brown colour. Decolorized by H_2O . (Turns ferrous sulphate solution brown.)
NH ₃	$2\text{NH}_4\text{Cl} + \text{Ca}(\text{OH})_2 = 2\text{NH}_3 + \text{CaCl}_2 + 2\text{H}_2\text{O}$	(a).III	Smell. Alkaline reaction. Blue precipitate with CuSO_4 solution.
PH ₃	$4\text{P} + 3\text{NaOH} + 3\text{H}_2\text{O} = \text{PH}_3 + 3\text{NaH}_2\text{PO}_4$ Pass inert gas through	(b).II	Smell. Burns forming P_2O_5 .
CH ₄	$\text{CH}_3\text{COONa} + \text{NaOH}$ ^{heat} $\text{CH}_4 + \text{Na}_2\text{CO}_3$	(a).II	Burns with luminous flame $\rightarrow \text{CO}_2 + \text{H}_2\text{O}$. Not absorbed by bromine-water.

FIGURE 30.—Chart of the preparation of and tests for gases

and beehive shelves are replaced by beakers, or sinks with specially designed shelves; gas-jars by test-tubes; test-tubes by ignition-tubes. The small-scale apparatus may often be held in both hands by the experimenter until the reaction is completed. Otherwise it may be held in position by a test-tube holder or by a small retort-stand. Special apparatus may be designed and made by ingenious pupils in the workshop or elsewhere. Efficient substitutes for bosses and clamps are fashioned from clips, screws and sprung clothes-pegs. A combined test-tube rack and stand is shown in Figure 29. The wooden rack holds four small test-tubes, and one end is extended and mounted with a bent strip of copper to support a test-tube. The delivery tube passes into another test-tube, or merely impinges on a glass slide bearing the reagents.

Deflagrating spoons are constructed by coiling wire into the form of an inverted hollow cone and soldering the straight piece into a metal disc. A deflagrating spoon for sodium is made with the help of a lathe. Holes are bored in a small hollow cylinder and this is sealed by a screw joined to a piece of wire which is bent at right angles.

A revision chart for the preparation and properties of the commoner gases

The chart, Figure 30, might be drawn up by each pupil as a concluding revision and summary in the final year. It might be set for

preparation in the last term before an examination, as it provides an excellent revision exercise. Many of the tests given, and alternatives, might be carried out by small-scale methods when solving practical problems.

Small-scale methods for juniors

The training that juniors receive in their first two years of Chemistry does much to influence their experimental technique. In consequence, emphasis should be placed on correct procedure.

The general principles of small-scale methods should be stressed in the early experiments on solubility, alkalis, bases and acids. Drops

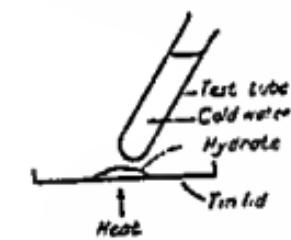


FIGURE 31.—Condensation of water evolved from a heated hydrate

of the three mineral acids may safely be removed with a glass rod and placed separately on strips of wood, paper, cloth, and into a concentrated solution of sugar and water (to note the heat evolved and to form their dilute solutions). Drops of the dilute acids may be run into drops of silver nitrate, barium chloride and sodium carbonate solutions and, for tasting purposes, into water. Such modifications with similar experiments require no elucidation (e.g. Figure 31). Other ex-

periments, however, need an entirely different technique, and this is instanced by tests carried out with a gas which is allowed to flow from a delivery tube over rows of drops of reagents. Thus, a series of tests with hydrogen sulphide can be observed simultaneously by placing solutions of litmus, potassium permanganate, and salts of lead, cadmium, mercury, copper, arsenic and antimony on one glass slide (compare Figure 32). Care must be taken that the drops are not confused. This difficulty may be overcome by inserting a piece of paper underneath the glass slide, and numbering each drop (see Figure 35).

All the experiments on the preparation of gases may be done with the standard fittings described. Long pieces of string are preferable to wooden splints, when small-scale tests for support of combustion and inflammability are carried out in small test-tubes. Reduction tests are done with pieces of charred wood instead of charcoal blocks. A small tin can be partly filled with sawdust, or small pieces of wood,

and after puncturing the lid with several small holes can be strongly heated. The tin serves as a substitute for a retort. Inflammable gases

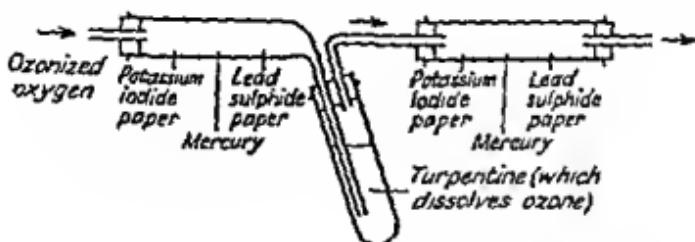


FIGURE 32.—An experiment with ozone (small-scale apparatus)

are evolved, and can be burnt at the holes, whilst wood charcoal remains.

Beginners often obtain poor results, and in these small-scale experiments it is possible to avoid waste of time and material by repeating the same experiments several times. An example is the 'brown ring' test for a nitrate, which can be quickly repeated on a tile, success being attained by slight variations of the conditions.

The following are other instances of modifications of conventional experimental methods:—An effective small-scale demonstration of the oxidizing powers of concentrated nitric acid is shown by pouring the acid on to a warm heap of sawdust in a crucible lid. In the preparation of prismatic sulphur, it is preferable to use either a cardboard or paper funnel instead of the cumbersome Battersby crucible or evaporating basin. The molten sulphur can be poured into the funnel from a test-tube, and, after the crystals have been seen, the remaining sulphur can be poured back. A piece of glass tubing removes sufficient molten sulphur to demonstrate the burning of small samples and the sublimation of flowers-of-sulphur inside the tube.

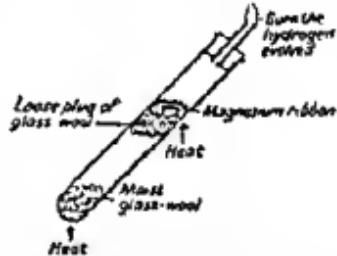


FIGURE 33.—The action of steam on magnesium: a small-scale experiment

Put a half-inch depth of water in a hard glass test-tube (4 x ½ in.), and soak it up with asbestos- or glass-wool. Warm the latter and ignite the magnesium. (To collect the hydrogen, hold the test-tube horizontal and pass the gas into another test-tube over water.)

The action of steam on magnesium can be clearly shown by boiling water in a silica test-tube, so that steam forms and passes over heated magnesium, supported on glass-wool near the mouth of the test-tube, where the evolved hydrogen can be ignited (see Figure 33).

Large test-tubes or boiling-tubes may be substituted for flasks in preparing gases. Hard-glass test-tubes may replace crucibles in quantitative work. For instance, copper is weighed in the test-tube (containing asbestos-wool, a cork and tube) and dissolved in the least amount of concentrated nitric acid. After heating, copper oxide remains and the whole is weighed. If necessary, the oxide may be reduced to copper by coal-gas in the same test-tube (see Figure 23).

Outline of problems and experiments.—(Tests are carried out with one drop of solution unless otherwise stated.)

(i) *Acids and carbonates.*—Action of sodium carbonate on dilute mineral acids—tests for carbon dioxide by special 'drop' methods—

examination of crystals of the different salts formed—extraction of solutions of organic acids from fruits (lemons, oranges, grapes, apples, etc.)—examination for crystals—action of these organic acids, as well as acetic, tartaric, and citric, on sodium carbonate—crystallization—taste, action on indicators and traces of metals—comparison of inorganic and organic acids—tests for acid in various common commodities such as cream of tartar, lemonade powders, sour wine—action of any one acid on different carbonates, baking-soda, mortar, different forms of calcium carbonate, 'soap-powder', sea-shells, egg-shells, plant ashes—flame tests for sodium, potassium and calcium—connect with, and make samples of, 'Health Salts' and Seidlitz powder—use of standard fittings and drops of lime-water to show formation of calcium carbonate and calcium bicarbonate.

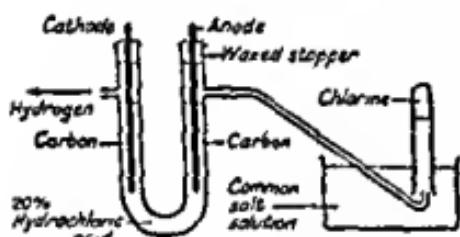


FIGURE 34.—The electrolysis of concentrated hydrochloric acid solution (small-scale). The batteries should supply about 16 volts

action of any one acid on different carbonates, baking-soda, mortar, different forms of calcium carbonate, 'soap-powder', sea-shells, egg-shells, plant ashes—flame tests for sodium, potassium and calcium—connect with, and make samples of, 'Health Salts' and Seidlitz powder—use of standard fittings and drops of lime-water to show formation of calcium carbonate and calcium bicarbonate.

(ii) *Copper and its compounds.*—Action of sodium hydroxide and ammonium hydroxide solutions on copper sulphate solution—com-

parison of, and reason for, any differences in colour with excess reagent—copper hydroxide and cuprammonium compounds—action of various strengths of sodium hydroxide and ammonium hydroxide solutions on speck of copper—solution of copper in concentrated nitric acid and neutralization with alkalis—tests for presence of copper salts in copper ores, Bordeaux mixture, blue water of swimming-pools, tinned green peas, bronze, brass, coinage, gold articles—precipitation of copper hydroxide, solution in ammonium hydroxide—examination of cotton-wool (cellulose) under microscope and solution in cuprammonium solution—examination of this treacly semi-solid mass under microscope—precipitation of cellulose by acid (now of little importance in the artificial silk industry except for a special type of artificial silk).

(iii) *Iron and its compounds*.—Action of crystal of ferrous sulphate on alkalis as above—action of air—differences between ferrous and ferric salts—other differences—solution of iron in acids—tests for iron in salts stocked in laboratory and in iron ores, iron pyrites (in coal), sea-shells and sand.

Small-scale methods for more advanced students

Many experiments in the advanced course may be carried out as described for the junior stage, so that the appropriate small-scale methods mentioned earlier are applied in studying substances such as bromine, iodine, carbon monoxide and ammonia; in testing for hydrofluoric acid; and in observing vigorous oxidation experiments with concentrated sulphuric acid and potassium chlorate. Pupils must be warned of the danger of repeating these experiments on a large scale.

Another illustration of the convenience of small-scale apparatus is in its application to electrolytic experiments. It is possible for pupils to demonstrate 'electric writing' by touching blotting-paper, soaked in solutions of sodium chloride and phenolphthalein, with the ends of wires connected to a flash-lamp battery. The sodium hydroxide, formed by the secondary reaction, affects the indicator and a red colour results around the cathode. Small U-tubes, or bent glass tubing, carbon electrodes (from flash-lamp batteries), and solutions of different salts (and concentrated hydrochloric acid), may be used in a series of experiments in electrolysis (for example, see Figure 34).

It should be noticed that small-scale chemistry permits the use of platinum wire in place of the more costly foil commonly used for electrodes.

Another particular advantage of these methods is in simple qualitative tests for acidic and basic radicals, when it is necessary to carry out several tests on one solution, e.g. in testing for a chloride and a sulphate. The method recommended is to put several separate drops of the test solution on to a slide, to place drops of the reagents opposite to them, and to draw each pair together with a glass rod. Several tests are carried out in a few seconds, and the different results for the simple radicals are quickly observed (see Figure 35). Many qualitative tests—flame, borax bead, charcoal block—are always

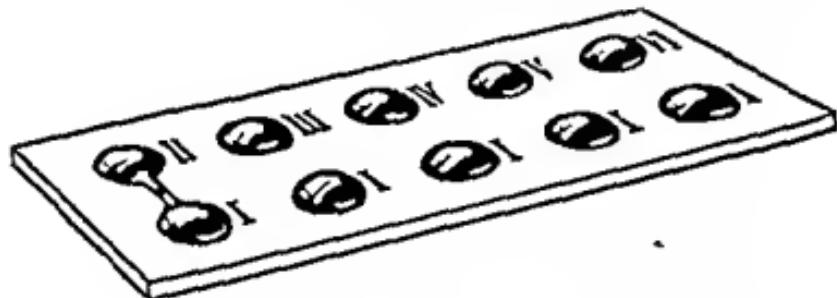


FIGURE 35.—A method of rapid qualitative testing for radicals

carried out on the small scale. If a microscope is available students can examine crystals of sodium chloride when the class is analysing sea-water. Each student can be called up in turn to view the crystals. Again, when oxygen is being prepared, a pupil who completes his experiment quickly may show the growth of the differently shaped crystals of potassium chloride and potassium chlorate with the help of a micro-projector.

Helpful small-scale experiments can often be made by students as introductions to more elaborate demonstrations. Thus, drops of concentrated ammonium hydroxide solution may be added to a test-tube of chlorine before the volumetric composition of ammonia is demonstrated by the teacher.

The majority of teachers in England believe that small-scale methods cannot be applied to every experiment, and that no attempt should be made to displace large-scale experiments completely. Each

student should gain experience in handling apparatus for measuring and preparing large volumes of gases. The use of distillation apparatus, filter-pumps, muffle furnaces and crucibles provides exercises valuable for their own sake and essential for external practical examinations. On the other hand, an increasing number of teachers, especially in the U.S.A., are convinced that the small-scale technique can be applied successfully to most of the individual experiments in general Chemistry. Excellent text-books are available in that country, and manufacturers are producing sets of apparatus suitable for small-scale, semi-micro-, and micro-Chemistry.

Later years should include a higher proportion of quantitative analysis. This work cannot be carried out satisfactorily in the school laboratory by small-scale methods. Some few modifications in the construction of apparatus may, however, be suggested. In equivalent determinations, test-tubes and boiling-tubes may be substituted for flasks; two burettes may be joined by rubber tubing and used as a Hempel burette (see Figure 12); and the usual experiment on the displacement of copper from copper sulphate may be extended to qualitative experiments with other metals and salt solutions.

Copper may be converted to copper nitrate and, in turn, to copper oxide by carrying out all the operations in one test-tube. The long combustion tube used in reduction experiments may be replaced by a hard-glass test-tube:— a small hole is blown out at the end of the test-tube, excess hydrogen is burnt at the hole, and the oxide is placed in a small copper-foil boat (as in Figure 23 (c)).

Further modifications in experiments using small-scale apparatus.— Certain large-scale experiments which are unsatisfactory may be replaced by small-scale experiments. Not only can several tests be done simultaneously by the changed method, but a reaction occurring in a thin film appears slower, and is therefore easier to study, and also the strength of the reagents used can be varied more readily to fulfil special conditions. Experiments which are effectively carried out with drops are the following: identification of potassium salts by means of potassium hydrogen tartrate and methylated spirits, and the formation of the blue solution of 'perchromic acid' with hydrogen peroxide, potassium dichromate solution, ether and dilute acid. The law of mass action may be demonstrated by varying the strengths of

solutions of potassium thiocyanate and ferric chloride, in order to alter the equilibrium between the two reactants.

Again, sufficient material for a large advanced class is provided by test-tubes full of saturated solutions of salts for use in experiments illustrating the common ion effect. For example, solutions of various chlorides (including hydrochloric acid) are added to a saturated solution of barium chloride, in order to observe the lowering of the solubility of this salt. Many experiments with common anions and cations can be carried out quickly, and the precipitate can be examined for crystal formation. It might be mentioned that the microscope can be used to examine the growth of crystals from molten solids (potassium nitrate or lead nitrate), and from different solvents (comparison of the growth of crystals in water and gelatine 'solution').

In addition, small-scale experiments illustrating the preparation of such compounds as potassium permanganate and amyl butyrate may readily be devised by pupils. Small-scale preparations of esters, for example, supply a number of facts and require such a varied technique that they might well be substituted for one long tedious experiment.

Most of the apparatus required in the advanced work is similar to that mentioned earlier in this chapter. Some few experiments may require heat. A crucible serves for tests in which sublimation occurs or a gas is evolved. It can be held in a wire ring and handle (Figure 17 (b)), and the wire can also hold a glass slide in position over the mouth of the crucible. A drop of liquid can be suspended on the underside of the slide while the reaction proceeds. If the liquid on a slide requires to be concentrated, or a reaction needs speeding up, careful heating is necessary. The Bunsen burner flame is turned down as low as possible, and the slide is held in the warm air only. In other cases it is possible to use warm metal plates or steam as sources of heat.

Outline of further experiments

(i) *Starches and sugars.*—Starch—examination of various samples (rice, wheat, maize, potato) under microscope—making 'solution'—iodine test and action of heat—tests for starches in common substances (sago, rice, beans, root-vegetables, custard-powder, dried soap)—action of heat on starch—dextrin conversion of starch into

sugars by dilute acids and enzymes. Sugars—comparison of solubility, sweetness, crystalline form of lactose, fructose, glucose and sucrose—special uses—reduction tests with Fehling's solution and 'silver mirror test'; comparison of action of different sugars—extraction of sugars from fruits (raisins, grapes, dates), sweets, honey and molasses, and identification of sugar present—examination of yeast cells—conversion of sugar (from raisins, etc.) into alcohol by fermentation (both small- and large-scale experiments)—preparation of esters, and other tests for ethyl alcohol.

(ii) *Metallic 'trees'*.—(A series of experiments on the action of metals on solutions of metallic salts.) Action of different metals (iron, magnesium, aluminium, tin, lead, mercury, etc.) on 10 per cent. solution of copper sulphate—examination for deposit of copper and disappearance of metal (examine under lens or microscope)—attempt to arrange metals in order of their activity—repeat with solution of lead acetate and different metals—then action of metals on solutions of silver nitrate, mercuric chloride, ferric chloride, aluminium chloride, lead acetate, cobalt nitrate, manganese sulphate, etc.

General precautions.—1. Use various strengths of salt solutions.
 2. When test is complete, examine solution for salt formation.
 3. If a compact piece of metal is ineffective, try turnings, filings, foil, etc.
 4. Impurities in the metals may influence the changes. Clean surfaces with sandpaper, or chemically.

5. Some salt solutions are not neutral, therefore neutralize before adding free metals such as magnesium. (In some cases, however, the hydroxide may be precipitated.)

6. Large crystals form in solutions with absence of vibration, with slow evaporation, and in deep drops. The conditions must make for the slow growth of crystals. Drop the metal either in the centres or at the sides of large drops. Use glass slide or small watch-glass. Examine for crystals of metals and salts.

7. Aluminium may give abnormal results because it is coated with a protective layer of aluminium oxide. The latter can be removed by rubbing with mercury or a solution of mercury salts. These protective coatings interfere with the results given by other metals.

The order of the metals in the electromotive force series is

potassium, sodium, calcium, magnesium, aluminium, manganese, zinc, iron (ferric), cobalt, nickel, tin, lead, hydrogen, copper, mercury, silver, platinum and gold.

(iii) *Osmosis*.—Series of experiments on silica 'water-gardens': action of small pieces of salts of nickel, magnesium, cobalt, manganese, copper, iron, etc., on solutions of sodium silicate—speed of growth—chemical action and osmosis—formation of semi-permeable membrane—copper ferrocyanide and ferric ferrocyanide membrane—'delaying' actions with gelatine and potassium ferrocyanide; sugar and copper sulphate—biological examples—action of water and sodium chloride solutions on hollow flower stalks and sections of beetroot—action of poisons, e.g. copper sulphate, potassium cyanide and methylated spirits, on sections of beetroot—similar experiments with algae—remove shell from bird's egg, try action of water and salt solutions, with and without manometer attached—references to more usual osmotic pressure experiments.

After the junior stage the student is more proficient in experimenting, and in consequence secures better results with specialized small-scale methods. It is necessary to state again that the pupil should receive systematic training in the use of every type of apparatus. It has already been stated that many teachers believe that small-scale methods should not, and indeed cannot for several reasons, be the usual method of carrying out practical work. Firstly, some branches of micro-chemistry are too technical and specialized, and are beyond the skill of pupils, who are unable to acquire the necessary technique in handling accurate instruments and sensitive reagents. Secondly, the reagents and apparatus required in some of these tests are too expensive, and the chemistry of the reactions themselves is too complicated for school purposes. Thirdly, sufficient time cannot be given to small-scale methods, as other experimental work is more important, and it is also impossible to use these methods in some experiments or in examinations. Small-scale methods cannot replace the large-scale preparation of pure organic substances, and exercises in volumetric and gravimetric analysis.

Other teachers have shown, however, that much time can be saved by applying these newer methods to qualitative work. Pupils who definitely prefer small-scale methods and secure reliable results

should be encouraged to extend their investigations. Enthusiastic supporters of small-scale chemistry assert, from their experience, that most of the usual experiments are best replaced by the use of small-scale equipment. The routine and mechanical methods of the older type of work are avoided, and greater accuracy is encouraged. In areas where there is a shortage of apparatus and equipment, it is strongly advised that the small-scale methods should be tried out and fostered. (See Appendix B 5, p. 277, for list of reference books.)

CHAPTER IX

The Teaching of Chemical Theory

Descriptive Chemistry

Descriptive Chemistry can be taught with little or no reference to the atomic theory and its applications. In secondary schools, however, Chemistry is taught as a science, and this means that a discussion of the atomic theory cannot be omitted.

The stage at which symbols, formulae and equations are introduced into school courses varies widely. Some teachers expect their use from the earliest lessons with bright pupils, believing that they serve as algebraic summaries. These teachers argue that the correct meaning of an equation is only understood by the pupil when it is studied again in the light of increased knowledge, and that equations are invaluable for revision purposes.

Other teachers, however, discourage the use of formulae as a substitute for the written word in the first year. They believe that a sound foundation of facts based on practical work is necessary before symbols, formulae and equations are mentioned.

It must be remembered, however, that while some pupils begin Chemistry at about twelve years of age, a few do not begin until they are fifteen. It is only fair to surmise that certain text-books, which introduce formulae and equations in their early pages, are written for these older pupils. The discussion in this chapter will be confined to the groups beginning Chemistry at about twelve years of age, i.e. at the beginning of the secondary stage of education.

It is only after much practice that the average schoolboy can write out ordinary equations correctly. Since precision in thinking is essential, and since first- and second-year pupils rarely grasp the full meaning of the symbols and formulae, it is inadvisable to allow the use of formulae as a sort of shorthand. Thus, statements such as 'Pour conc. HCl on MnO₂, heat, Cl₂ evolved and manganese chloride plus H₂O formed' should never be permitted at this stage. Less intelligent young pupils often attempt to use this incorrect method in the belief that time is being gained. They do not realize

that bad habits are being formed. Exceptionally bright pupils may adopt the correct method of dealing with formulae and equations in the earliest lessons without prompting. These pupils might be helped individually and encouraged in their efforts. The general rule is, however, that the average pupil should only be introduced to the atomic theory, symbols, formulae and equations by definite lessons in the second and third years.

Atoms and molecules

In the first year it is inadvisable to discuss the existence of atoms and molecules, except in an extremely elementary manner, and the treatment should be incidental and subsidiary to the main work. No attempt should be made to give the formulae, for example, of the different classes of iron and copper salts, nor should any attempt be made to give the formulae of compounds such as phosphorus pentoxide or potassium chlorate.

The pupils' own experiments show the broad differences between the mixture of iron and sulphur and the compound ferrous sulphide. The synthesis of the compound can be represented by an equation in words—iron and sulphur form iron sulphide (or ferrous sulphide). As mentioned earlier, individual pupils who, on their own initiative, use symbols and equations correctly should not be discouraged. This branch of the work, however, is not discussed in class. All pupils must be told that the equation states that iron combines, or reacts, with sulphur to form ferrous sulphide. The definitions of atoms and molecules should be left until later years, as they are too difficult for first-year pupils to understand.

Pupils should be introduced later to the three-dimensional concept by the use of pins, or matchsticks, stuck in clay or plasticine balls, or in small potatoes, fruits or seeds. Circles of cardboard joined by paper fasteners are not to be recommended. Atomic models may be bought, but more effective ones may be made from wooden balls of up to four inches in diameter. Two, three or four¹ holes should be bored in the balls in symmetrical positions, and long thin rods of wood

¹ This enables valency 'bonds' to come out at the angles corresponding to the corners of a tetrahedron. These atomic models can then be used in Organic Chemistry to demonstrate stereoisomerism, the benzene ring, etc.

inserted to give the idea of monovalent, divalent, trivalent and tetravalent (or univalent, bivalent, trivalent and quadrivalent) elements. The changes occurring in simple reactions should be illustrated by these models. Opportunity should be taken not only to introduce this work at every convenient stage in future lessons, but also to use it to revise earlier material in a systematic way.

Equations illustrated by models, for example, may be used to summarize the oxidation of magnesium, the heating of mercuric oxide, the heating of calcium carbonate, and the preparation of hydrogen. Later, the laws of constant composition, multiple proportions and conservation of mass, and the atomic theory and equivalent weights may be introduced. The laws must be supported by results obtained in the laboratory, and, whenever possible, must be linked with any relevant work which follows. The atomic theory may be surveyed briefly from the historical aspect, and when the principles have been learnt, they should be applied to a further understanding of the laws. The definitions of atom, molecule and symbol are then given, and a list of the simpler symbols is learnt by the pupil.

Symbols, formulae and valency

Many pupils find this branch of the subject very difficult to understand. It is sometimes necessary to split the class into two divisions: one division which builds up formulae and equations with moderate ease, and the other which finds great difficulty in balancing simple equations even when taught by drill methods.

The pupils are introduced to the idea of valencies by using coloured balls joined on to one, two, three, four or five other balls. The terms atom, molecule, symbol and formula are each illustrated by these concrete models. Then the commoner elements and radicals of the same valency are grouped together and arranged under two headings, positive and negative.

The models show that an atom of a monovalent metal such as sodium, having one valency bond, can be joined to one radical only of chlorine to form a molecule of sodium chloride. The principle of formation of compounds from one atom of a monovalent metal with one monovalent acidic radical, or one atom of a divalent metal with one divalent acidic radical, or one divalent atom with two monovalent atoms, and so on, is developed by oral work in class. Mech-

Valency	Positive		Negative	
I (mono- or univalent)	Sodium (Cuprous Ammonium (Mercurous Potassium Silver	Na— Cu— NH ₄ — Hg— K— Ag—	—Cl —NO ₃ —HCO ₃ —OH (—NO ₂ (—HSO ₃ (—HSO ₄	Chloride Nitrate Bicarbonate Hydroxide Nitrite) Bisulphite) Bisulphate)
II (di- or bivalent)	Magnesium Calcium Zinc	Mg< Ca< Zn<	>O >S >SO ₄ >CO ₃ (>SO ₃	Oxide Sulphide Sulphate Carbonate Sulphite)
III (tri- or tervalent)	Aluminium Iron Ferric	Al< Fe<	>PO ₄	Phosphate

FIGURE 36.—Valency chart for the commoner radicals

anical exercises are necessary until the art of building up formulae is completely mastered. The straightforward method of memorizing the valencies of the commoner radicals may be used, and plenty of exercise given in building up the formulae of simple compounds. At a later stage the theories of electrovalence, covalence and co-ordinated valency may be dealt with. If such methods are not used, the pupil may be bewildered by the mass of symbols placed before him. Such factors as the length of the course, the age of the pupils, etc., should be taken into account in deciding upon the method of treatment of this subject. The more mature chemist appreciates the significance of symbols and equations, but the beginner is faced with many difficulties. Fixed valencies, variable valencies, the number of atoms in a molecule, the method of representing metals as monatomic, the vague use of 'equal' and 'plus' signs, the lack of quantitative values, the omission of details of the physical state of the reactants, the apparent

similarity to algebraic symbols, and the balancing of equations are serious problems to the immature mind. The young teacher must take these questions into consideration during the earlier years when formulae and equations are being taught.

Care must always be taken with juniors to point out that $-\text{HCO}_3$ (bicarbonate), and NH_4^+ (ammonium), are *radicals* and cannot exist alone but only as part of a compound.

Further, it should be noted that most metals have a valency of two, and this generalization might be used in early lessons and the exceptions noted, i.e. monovalent SAPS, as in the chart (if cuprous copper and mercurous mercury are included, SCAMPS); trivalent, aluminium, ferric iron and phosphate; and quadrivalent, carbon and silicon. Later, pupils will encounter elements with variable valencies such as copper and mercury, mono- or di-; iron, di- or tri-; tin, lead and sulphur, di- or tetra-; and phosphorus and nitrogen, tri- or penta-valent. Young teachers must also be prepared for questions from pupils, who may ask for such information as the valency of iron in Fe_2O_4 and of oxygen in H_2O_2 . Further problems will be solved when advanced pupils learn the modern conceptions of valency—electrovalency and covalency.

It is advisable to give pupils exercise in reading symbols and in stating the full meaning, for example, of 3Na , H_2 and 5O_2 .

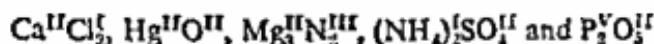
Several methods might be used in introducing formulae:—

(a) In the first place, atomic models, with valency bonds attached, show pupils the need for satisfying the valencies of each atom in building up the formula for a molecule of a compound. Thus, the two valency bonds of two monovalent chlorine atoms satisfy the two bonds of one divalent atom of magnesium, forming one molecule of magnesium chloride.

(b) A second method is to show, for example, that the formulae of salts and oxides may be built up theoretically from those of water and the acids. Thus, the formula for hydrochloric acid, HCl , may be a useful starting-point for the formulae of all the chlorides. Monovalent elements form chlorides of the class represented by XCl , divalent elements form chlorides of the class XCl_2 , trivalent elements, XCl_3 , and so on. Similar examples should be worked out for the sulphates, nitrates, oxides, etc.

(c) A third method is to write down the symbols for the atoms

and radicals, and to show that in a compound the valency of each atom (or radical) multiplied by the number of each must give the same value. In calcium chloride the calcium atom is divalent, and the molecule contains one calcium atom. The chloride radical is monovalent, therefore there must be two chlorine atoms in the formula of the molecule CaCl_2 . Alternatively, the pupil might be shown this simple relationship by the temporary use of Roman figures for the valency:—



Common (i.e. popular) name	Chemical name	Formula
Baking-soda	Sodium bicarbonate	NaHCO_3
Black-lead; plumbago	(Graphite, a form of) carbon	C
Bleaching-powder; chloride of lime	Mixture: chiefly calcium hypochlorite and basic calcium chloride	—
Blue vitriol	(Hydrated) copper sulphate	$\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$
Brass	(An alloy of) copper and zinc	— (Cu & Zn)
Brimstone	(Roll) sulphur	S
Brine	(Concentrated or saturated solution of) sodium chloride (in water)	NaCl
Carbide	Calcium carbide	CaC_2
Caustic soda	Sodium hydroxide	NaOH
Chalk	(A natural form of) calcium carbonate	CaCO_3
Epsom salts	(Hydrated) magnesium sulphate	$\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$
Hypo (hyposulphite)	(Hydrated) sodium thiosulphate	$\text{Na}_2\text{S}_2\text{O}_4 \cdot 5\text{H}_2\text{O}$
Lime-water	(An aqueous solution of) calcium hydroxide	$\text{Ca}(\text{OH})_2$
Plaster of Paris	(Hydrated) calcium sulphate	$2\text{CaSO}_4 \cdot \text{H}_2\text{O}$
Potash	Potassium carbonate	K_2CO_3
Quicklime	Calcium oxide	CaO
Quicksilver	Mercury	Hg
(Common) Salt	Sodium chloride	NaCl
(Chile) Saltpetre	Sodium nitrate	NaNO_3
Slaked lime	Calcium hydroxide	$\text{Ca}(\text{OH})_2$
(Cane) Sugar	Sucrose	$\text{C}_12\text{H}_{22}\text{O}_{11}$
Sulphuretted hydrogen	Hydrogen sulphide	H_2S
(Washing-) Soda	(Hydrated) sodium carbonate	$\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$

FIGURE 37.—A chart of the chemical names and formulae of some common substances (see also p. 290)

All three methods should be used. The first and third are useful for oxides, sulphides, and other binary compounds; the second is available for salts of oxyacids, and introduces the idea of substitution.

Pupils must realize that the three methods are only teaching-devices. In the first case, it must be pointed out that there are no material valency 'links' or 'bonds', although pupils may be told later that in some cases it is considered that 'bonds' exist¹; in the second case that the theoretical displacement of hydrogen from the acids may not occur in practice; and in the last, that the Roman figures must later be deleted. Thus, the idea can be introduced that valency is not merely a mathematical convention, but is a constitutional property of the atoms concerned.

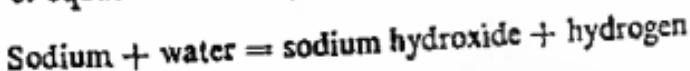
A much longer list than that of Figure 37 is given in Appendix F, p. 290, and it could be extended still further. Lists of this kind are useful in many ways:—as revision charts, especially when made under selected headings; as summaries and as memory-aids; for development as wall-charts, etc. Similar lists may be prepared for such subjects as:—common ores; principal sources of elements (or metals or non-metals); precious stones; alloys, etc. Additional or alternative columns may be introduced:—e.g. for method of preparation; manufacture; chief properties; important uses, etc. Pupils should be encouraged to make brief classified lists for individual and class use.

Errors made by pupils in constructing equations

Although mistakes in equation-building are often due to carelessness or insufficient practice, even pupils of average intelligence and industrious habits encounter many obstacles when learning this branch of theoretical Chemistry. It is especially important that equations should not be read mechanically so that the 'plus' and 'equal' signs are misinterpreted and given an algebraic meaning.

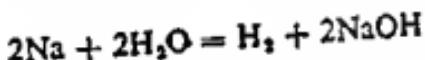
¹ Covalent compounds possess a bond in the sense of, presumably, a pair of shared electronic orbits. The mechanism by which this effects a link is not precisely known. The link is directed, requires considerable force to distort it, is only extensible to a very small extent, and in fact behaves very much like a stiff spring. Electrovalent compounds such as salts have merely an electrostatic attraction. Consequently, as long as the distance between the atoms is not increased, it does not resist relative motions of the radicals.

If incidental teaching of this branch of Chemistry is necessary in the first year, pupils should be discouraged from writing modified versions of equations of the type:—



It should later be explained that the first 'plus' sign stands for 'reacts with', and the 'equal' sign for 'forms'. Thus the pupil should read the reaction as 'Sodium reacts with water forming sodium hydroxide and liberating hydrogen'. Equations representing only part of a reaction should not be attempted, even in simple verbal form, for equations should be taught as a complete summary of the chemical changes actually seen by the pupil. He should be able, in time, to connect much practical information with the bare facts stated.

Later, other points should be discussed and greater accuracy expected. The equation for the above reaction is then written in the correct way:—

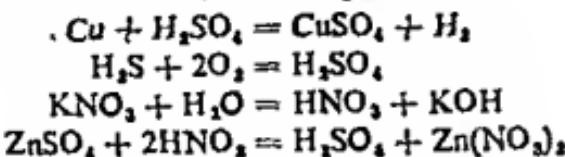


and the reaction must be thought of in terms of atoms and molecules. At the same time pupils should be told that millions of atoms and molecules are reacting, but that the practice is to represent the change by the smallest relative numbers of complete molecules. As the practical work proceeds, questions of valency, amounts of reactants, conditions, balancing, and the physical states of the reactants must also be discussed in conjunction with the use of equations.

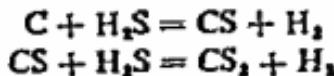
After much individual study and practice in building equations, theoretical problems may be set. Then it must be emphasized that, even if an equation for a reaction can be written down and balanced, it does not justify the conclusion that it will occur in practice. Constant reference to experiments must be made in order to avoid such assumptions. The point must repeatedly be made that an equation summarizes a reaction which has occurred, and that a chemical change will not take place merely because an equation can be balanced.

Examples from pupils' note-books.—Examples of the incorrect use of equations which balance, but do not actually occur, are frequently

given in pupils' note-books; for example:—



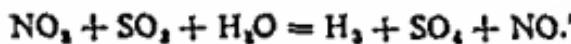
One pupil gave the following method for the preparation of carbon bisulphide from carbon and hydrogen sulphide by using the two stages



Another pupil stated that hydrochloric acid gas fumed when it came in contact with his breath because of the following reaction:—



A third pupil, in his description of the lead-chamber process, wrote:— 'What actually happens is that the oxygen in the steam combines with one part of the nitrogen peroxide forming O_2 from the O and O. This combines with the O_2 in the SO_2 forming O_4 . The hydrogen from the H_2O and the S of the SO_2 form the rest of the equation:—



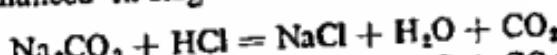
Incorrect equations showing difficulty in appreciating the use of formulae frequently occur in pupils' note-books. For example:—

1. $\text{CaO} + 2\text{HCl} = \text{CaCl} + \text{H}_2\text{O}$
2. $\text{Mg} + \text{H}_2\text{SO}_4 = \text{MgSO}_4 + 2\text{H}$
3. $\text{Na} + \text{H}_2\text{O} = \text{H}_2 + \text{NaO}$
4. $\text{NaCO}_3 + 2\text{HCl} = \text{NaCl} + \text{H}_2\text{O} + \text{CO}_2$

The points to be noted in connexion with the above are:—

1. shows that the young teacher should repeatedly warn his pupils that 2HCl represents two molecules of hydrochloric acid (i.e. $\text{HCl} + \text{HCl}$) and not two atoms of hydrogen and one atom of chlorine;
2. shows the tendency to write down free atoms of a gas; it should be pointed out that the common gases which occur as elements are diatomic;
3. is an example of a balanced equation which will not occur in practice;

4. was 'balanced' in stages as follows:—



and then $\text{NaCO}_3 + 2\text{HCl} = \text{NaCl} + \text{H}_2\text{O} + \text{CO}_2$

In this case, for example, the mistake was made in thinking that two molecules of hydrochloric acid contained only one atom of chlorine instead of two, and in order to balance the equation the correct formula for the molecule of sodium carbonate was altered. It is especially important to keep the formulae of the molecules intact. Pupils often alter them for convenience when attempting to balance the equation.

Building up elementary equations

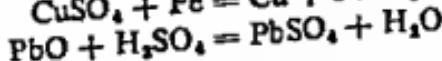
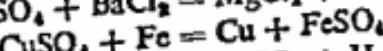
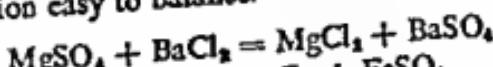
Some such procedure as the following must be brought to the notice of the pupils in writing equations.

(i) Write down the formulae of molecules of reacting substances on the left-hand side.

(ii) Write down the formulae of molecules of resulting substances on the right-hand side.

(iii) 'Balance' by making sure that the formula of completed molecules is *not* altered, that the number of atoms on each side is the same, and that there are no free atoms.

The pupil should be informed of the general principles involved. He should know the names of the salts formed from the acids and bases. It is surprising how much time must be spent in revising these elementary facts, and lack of knowledge of them is the cause of much uncertainty in equation-building. The fact that sodium hydroxide, for example, forms a series of sodium salts and that hydrochloric acid forms only a chloride (and not a hydroxide, chlorate or chlorite) should be instantly recalled by each pupil. In addition, he should be prepared for the occurrence of such reactions as double decomposition, displacement, and neutralization. These make the following types of equation easy to balance:—



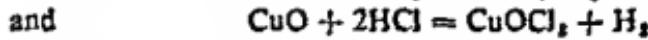
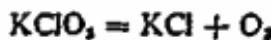
Again, it should be borne in mind that molecules of water are

often formed in chemical changes. The hydrogen and oxygen atoms must then be present in the ratio of two to one to form the molecules of water. This helps in writing the equation for the reaction between manganese dioxide and concentrated hydrochloric acid. The pupils should be able to write the correct formulae for manganese dioxide and hydrochloric acid and should know that chlorine and manganese chloride are formed. The two atoms of oxygen form two molecules of water and thus four molecules of hydrochloric acid are required, i.e.



Similar considerations apply to the action of other oxidizing agents on concentrated hydrochloric acid, and to reactions between ammonia and oxygen, copper oxide and ammonia, and the reduction of oxides by hydrogen.

Pupils should be told that equations must be written in terms of known substances with satisfied valencies. Errors such as



are more difficult to correct and they can only be avoided by experience.

More advanced equations

Equations are treated in outline when first introduced, but greater precision is expected in later years. Several of the points previously discussed will still be causing trouble. The teacher will probably find that some pupils are almost incapable of writing correct equations.

Increasing familiarity with symbols, formulae and equations makes it necessary to warn pupils that merely to be able to balance equations correctly is not learning Chemistry. Equations must be used as tools, and it must be understood that each symbol represents a definite weight of an element, and that the volumes of gases reacting and produced in an equation are clearly conveyed by their coefficients. It is advisable for the pupil to work out a number of suitable arithmetical problems. At first the arithmetical operations involved should be as simple as possible. At every stage the problems should be connected with the pupil's own work and whenever possible with everyday problems. Indeed, the solution of suitable problems in-

creases the pupil's knowledge of Chemistry, and makes him realize the advantages of learning the use of equations. He might attempt problems of the type:—

1. If 10 g. of pure marble are heated strongly, calculate the weight of (i) calcium oxide, (ii) carbon dioxide, formed. What weight of each is formed if 10 tons of pure marble are used?
2. What weight of slaked lime, $\text{Ca}(\text{OH})_2$, forms when 5.6 lb. of quicklime are slaked?
3. How much iron may theoretically be extracted from 1.6 tons of pure haematite (Fe_2O_3), and what weight of coke is required in the reaction, if it is assumed that the coke contains 85 per cent. carbon?
4. What weight of (i) sodium hydroxide, (ii) potassium hydroxide, (iii) calcium oxide, will individually neutralize 4.9 g. of pure sulphuric acid?
5. Calculate the weight of oxygen evolved by heating strongly 1 g. of mercuric oxide.
6. What weight of zinc is required to yield 2 litres of hydrogen at N.T.P., using excess of dilute sulphuric acid?
7. A shopkeeper left one pound of washing-soda exposed to the air so that a residue, $\text{Na}_2\text{CO}_3 \cdot \text{H}_2\text{O}$, remained, and he sold this for 6d. per lb. Which is the better value: the residue, or one pound of pure washing soda at 4d. per pound?
8. What volume in litres of twice-normal H_2SO_4 neutralizes 1 litre of N NaOH?

For the majority, however, the earlier treatment should be extended, so that pupils may be helped to realize that equations have limitations. An instructive discussion may be centred round this fact. The members of an intelligent class might make suggestions of the following type:—an equation gives no detailed information as to (a) The physical state of the chemicals, i.e. if they react as solid, liquid or gas.

- (b) Whether the change is reversible, i.e. if equilibrium is established.
- (c) The conditions for carrying out the reaction, e.g. if heat is required.
- (d) The time taken to complete the reaction.
- (e) Heat changes, i.e. if the reaction is endothermic or exothermic.

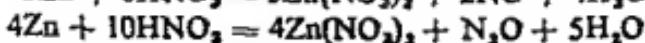
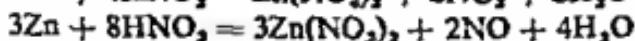
(f) The presence of another medium (usually water), in which reaction takes place, the effects it produces, or the concentration of the reactants in the medium.

Such criticisms help to show pupils that equations should be used as an aid only, and that standing alone they cannot supply complete information.

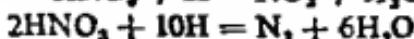
Misconceptions may come out during class discussion, after preparing crystals of magnesium sulphate by neutralizing dilute sulphuric acid with magnesium oxide. An entirely erroneous idea may be obtained of the quantity of water formed in such a change. Demonstrations of passing dry hydrochloric acid gas over a heated oxide show the pupil that little liquid water forms. Moreover, a chemical calculation shows that large volumes of hydrogen and oxygen must be burnt to produce any appreciable weight of water.

In summarizing the solubility of ammonia in water the pupils write the equation $\text{NH}_3 + \text{H}_2\text{O} = \text{NH}_4\text{OH}$, not realizing that only a fraction of the gas undergoes this chemical change and that most of it dissolves physically. Examples of similar changes will occur to the teacher, and in every case the pupil should be informed definitely and accurately of his errors.

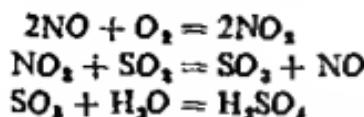
Later, the student discovers that both teacher and text-book may have used completed equations to summarize certain reactions which do not in fact occur. The action of concentrated nitric acid on zinc depends, for example, on the concentration of the nitric acid. A number of gaseous products result including NO_2 , NO , N_2O , N_2 , NH_3OH ; and although equations may be written for each stage it is usual for more than one reaction to occur simultaneously. Examples of such reactions are:—



Again, the formation of these gases is often explained by assuming that nascent hydrogen reduces the nitric acid. This is only a teaching device, and it is doubtful if the following reactions actually occur:—

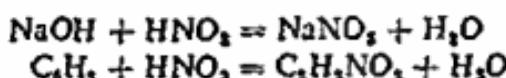


Many chemists doubt if the catalytic action occurring in the lead-chamber process for the manufacture of sulphuric acid occurs as follows:—



In balancing reactions involving a knowledge of more advanced Chemistry, a teacher might usefully draw on his experience to help students as follows:—

1. It should be shown that reactions in Organic Chemistry differ in certain respects from those occurring in Inorganic Chemistry. Clear explanations should be given of different types of general reactions with illustrative equations, e.g. substitution, addition, hydrolysis, acetylation, etc. Examples of reactions in Inorganic and Organic Chemistry, such as the following, should be compared:—



and the possibility discussed of the second reaction proceeding further, e.g. to give $\text{C}_2\text{H}_5(\text{NO}_2)_2$.

Again, chlorine displaces hydrogen stage by stage in benzene, forming $\text{C}_6\text{H}_5\text{Cl}$, $\text{C}_6\text{H}_4\text{Cl}_2$, $\text{C}_6\text{H}_3\text{Cl}_3$, $\text{C}_6\text{H}_2\text{Cl}_4$, C_6HCl_5 , C_6Cl_6 .

The existence of isomerism and the complexity of organic molecules should also be noted.

2. In advanced Chemistry equation-building becomes complicated when dealing with complex ions, i.e. carbonyl, cuprammonium, cobaltinitrite, ferrocyanide, ferricyanide, ammine, mercurio-iodide and double salts; for example:—



3. Certain reactions may be understood more easily by supposing that a molecule of the reacting substance is subdivided, e.g. 2KMnO_4 can be written as $\text{K}_2\text{O} \cdot 2\text{MnO} \cdot 5\text{O}$ showing that in the presence of dilute sulphuric acid:—



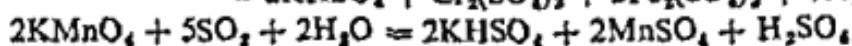
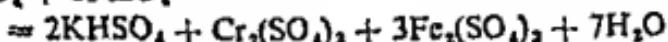
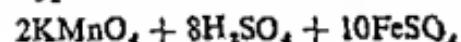
and that two molecules of potassium permanganate thus give 5 atoms of oxygen.

of oxygen representing 10 atoms of hydrogen; and therefore that the equivalent weight of potassium permanganate is

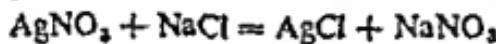
$$\frac{\text{molecular weight}}{10} = \frac{316}{10} = 31.6$$

Similarly $K_2Cr_2O_7$ can be considered as $K_2O \cdot Cr_2O_3 \cdot 3O$.

Typical reactions in volumetric analysis are therefore represented:—



4. Later, the student should be introduced to ionic reactions and instead of writing

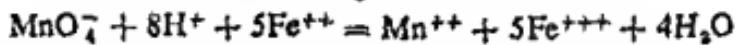


should write $Ag^+ + Cl^- = AgCl$

and instead of $Zn + H_2SO_4 = ZnSO_4 + H_2$



and the reactions in 3 above are given as follows:—



or $MnO_4^- + 8H^+ + 5e = Mn^{++} + 4H_2O$

Chemical equilibrium

The algebraic aspect of a chemical equation often makes a reaction appear too definite so that it tends to be regarded independently of the actual experiment. The dynamic point of view of reacting chemicals should be stressed. The action of steam on iron gives an early opportunity for explaining the nature of chemical equilibrium. Pupils should be shown that all four substances (iron, steam, iron oxide and hydrogen) are present, and that the first two are gradually used up as the change proceeds. The chance of a reversible reaction occurring may be mentioned when outlining in simple words the law of mass action.

Again, when marble is strongly heated with a blowpipe, the change must be pictured as a gradual one. The equation



represents the change on the outer surface of the marble only, as the remainder is still undecomposed. Gradually, however, the reaction is completed and quicklime remains.

In a similar way, many first-year pupils think that any reaction is instantaneous. They write a balanced equation, and believe, for example, that a piece of calcium carbonate neutralizes a test-tube half full of dilute acid in a few seconds. The best corrective is to demonstrate the action in order to show that the solution of the calcium carbonate takes several minutes.

Some examples might be specially considered in order to connect the gradual completion of reactions with their corresponding equations. In an experiment with carbon dioxide passing through lime-water, the gradual formation of calcium carbonate, or the disappearance of the calcium hydroxide, is shown by the increasing milkiness. The maximum turbidity can be roughly estimated, indicating the completion of the first stage:—



The excess carbon dioxide then slowly dissolves the precipitate, forming calcium bicarbonate. Finally, the action corresponding to the equation



is completed. The reverse action, giving calcium carbonate, can be shown by heating the calcium bicarbonate solution. It should be pointed out that these reactions are quantitative and attain completion slowly owing to the varying conditions. The carbon dioxide has a low solubility and there is only a small surface-area of solid carbonate upon which the reactions can take place (owing to the adhering bubbles of carbon dioxide, the sinking of the calcium carbonate, etc.).

It is useful to illustrate this reaction further by discussing the setting or hardening of lime-mortar, which is a gradual reaction between the carbon dioxide of the air and the slaked lime. Calcium carbonate slowly forms, but even after many years much of the slaked lime inside is still unchanged.

Alternatively, reference can be made to the steady completion of quantitative changes, owing to the conditions. Examples are: titration experiments with a solution of standard silver nitrate and a

solution of sodium chloride; the oxidation of mercury in air; or the heating of copper nitrate. When these experiments have been in progress for a short time the balanced equations show the state for only part of the substances which have reacted or decomposed, and until the exact equivalent quantities have reacted (or decomposed) the equations cannot be used in their entirety. It is wrong to assume that an equation represents an instantaneous reaction which is complete and definite.

Consideration of the kinetic theory of molecules might be attempted, with brighter classes, to illustrate other reactions. The theory should certainly be outlined when describing and explaining the diffusion of gases. It also helps in understanding the definitions of saturated solutions and other equilibria.

The atomic theory

The majority of Chemistry teachers continue to teach Dalton's modified atomic theory in the early years, the newer views of the electronic structure of the atom being postponed for three or four years. This method of treatment is advisable. The idea of small spheres representing atoms serves as a useful teaching device for most beginners. Later, the few individuals who specialize in Chemistry can readily modify their existing ideas according to the theory of electronic structure. In the rare cases where students begin the study of Chemistry at the university or technical college, there are fewer objections to introducing the electronic theories at once.

The young teacher must be prepared to answer awkward questions. Pupils criticize the definitions of atoms and molecules; they ask for details of the sizes of atoms, and they want information on the methods of determining these sizes; while other pupils find difficulty in grasping the conception of atoms and molecules and their reactions. Interesting comparisons of the sizes of atoms and molecules are given in text-books, and pupils thus gain some idea of their minuteness. Suitable reference books on this, and similar matters, should be kept in the school library.

Pupils find it difficult to understand the difference between the two definitions that: the smallest part of a substance to have a place in a chemical change is an atom, but the smallest part to exist alone is the molecule. Much repetition and explanation must follow before it is

realized that atoms of most gaseous elements (except the inert gases) cannot exist alone, and that the formula for the molecule represents two atoms.

More difficulties may arise when pupils try to correlate their practical work with so-called explanations offered by the atomic theory. This type of difficulty is not often met with, since the majority of pupils accept the explanations of teacher and text-book. Some of the more intelligent pupils, however, ask why the active element sodium forms inactive sodium chloride when it is burnt in the green poisonous chlorine. Why should carbon monoxide be poisonous and carbon dioxide not? Why is mercury a silvery colour and mercuric oxide red? Why is litharge yellow and the higher oxide red? It must be stressed that Chemistry describes rather than explains such changes. It might be stated that the properties of a compound are different from those of its elements—a mere description. Other pupils may be referred to the physical properties of different allotropes. Phosphorus is red or white, and one allotrope can be converted into the other. It has been suggested that the differences between the two may be accounted for by polymerization or polymorphism. Thus the colour of the individual atoms does not necessarily give the colour to the collective mass. The number and arrangement of the atoms and electrons no doubt influence the physical properties. Very little is known about the connexion between colour and structure, and the pupil should be told so.

It may be necessary to outline the above points to satisfy older inquiring pupils, and to admit that definitions of the chemical laws and the atom are being modified. At least a warning must be given to prospective teachers of the varied types of question asked by intelligent pupils. These questions must receive consideration and the inquirers must be satisfied as far as their knowledge and intellect permit. The teacher should not, however, hesitate to admit that certain facts are unknown or too difficult for him. If the latter admission is properly made, it indicates the vast extent of Science and not the ignorance of the teacher. An attempt to avoid answering gives a very bad impression.

Scientific doubt and attitudes

As previously mentioned, the law of constant composition and

other laws cannot be maintained with the same rigidity as they were in the last century. Students in senior classes must be introduced to the idea that elements have isotopes and that their existence modifies the simple definitions learnt in the early years. Thus, lead has isotopes of atomic weight 206, 207, and 208, and litharge may have a molecular weight of 222, 223, or 224.

It should be mentioned that in Science a 'law' is simply a statement of a scientific 'truth', i.e. it is a summary of the scientists' knowledge of a certain subject, and it is conveniently expressed according to contemporary ideas. (The law of a country or district, civil law, is quite different. It consists of rules made by man to control the conduct of individuals and society, and it is possible for these rules to be broken by accident or design.) A scientific law cannot be 'broken', because it is merely a *statement* of known facts and relationships. It is possible that at a later date such a statement may be proved incorrect, owing to new observations or the discovery of new facts—and then it has to be altered or abandoned.

Thus pupils see that scientific truth is limited in scope. A scientific law is a statement of what is likely to occur under certain conditions. Experiments have shown that it has been true up to the present, but future investigations may necessitate a modification and the formulation of a new law to fit the existing facts. The idea that theories, and even the laws and facts of Chemistry, are of a temporary nature should be put before the senior students.

Teachers should not pretend that Chemistry presents its knowledge with conclusiveness. Instead, stress should be laid upon the methods used by the early chemists in overcoming their difficulties. For example, until the compounds sodium hydroxide and potassium hydroxide were decomposed by the electric current they were thought to be elements. Such ideas were not permanent, but, like many of the older theories, were discarded after serving their purpose. The Chemistry teacher must point out continually, preferably with the use of examples, that Chemistry is always advancing: indeed, that it changes every day. Thus he can show that it is often impossible to explain fully, or solve a problem with precision, at a particular time. Influences are at work today which are modifying the views and opinions taught in schools, and this is especially noticeable in the effect of recent theoretical advances on radio-activity, the atomic

bomb, the structure of the atom, 'heavy' hydrogen, and high pressure and catalytic syntheses.

Thus, the teacher will lead the students to appreciate that Chemistry has its limitations. Its functions are concerned with rational values and devising techniques for material purposes. The methods of Chemistry are restricted and cannot be applied on their own to solve problems and interpret data concerned with morals, laws and politics. Properly taught, Chemistry, like other branches of Science and in conjunction with them, ought to help the student to think clearly and develop attitudes such as:—

Man's idea of truth is continually changing owing to new discoveries, inventions and ideas—what is accepted as a fact today may be rejected tomorrow—listen to the views of others, but do not accept them unless you have reason to believe they are correct—test opinions by experiment, observation and authoritative views—do not arrive at a conclusion without due consideration—find out which authorities are reliable and how to obtain the latest accurate information—chemists have many unsolved problems before them, but their successes up to date provide conclusive proof that their methods are sound—effects have causes; and orderliness, in general, prevails in Nature.

The teacher himself must believe in these generalizations, and must consistently apply them as part of his teaching technique. On occasions he should certainly list them for his students' consideration.

Modern research in Chemistry

The pupil should realize that, in their search for knowledge, chemists are both scrutinizing earlier work and preparing new compounds. Suitable training may lead the pupil to scan the scientific journals and to notice, for example, that oxides of fluorine were isolated in 1927 and 1933, and sulphur monoxide in 1933. On his own account he can (if necessary) bring the text-book information up to date, correcting the statement that fluorine will not form a compound with oxygen.

Certain text-book statements again are controverted by the comparatively modern research of Sir Charles Parsons. He criticized the work of Moissan on the conversion of charcoal into diamond, which

is still quoted in many Chemistry text-books. In his Bakerian Lecture to the Royal Society, 1918, he stated that:—

(i) If carbon is melted or vaporized under a pressure of 15,000 atmospheres it does not crystallize as Crookes and Moissan supposed it would.

(ii) Moissan's supposition that a great pressure was produced by quenching molten cast iron is erroneous.

(iii) If instead of quenching the molten iron, the mass is subjected to a pressure of 100 tons per square inch, less crystalline residue is obtained.

He concludes that diamonds have not yet been made in the laboratory, and that the investigators have been led into thinking that various transparent singly-refracting minerals, which happen to resist the action of drastic chemical reagents, are diamonds.

In 1936 Hershey, in the U.S.A., made many small diamonds by heating gum arabic and iron filings in an electric furnace at a temperature between $4,000^{\circ}$ and $5,000^{\circ}$ C. The largest weighed 0.03 carat ($= 0.00065$ g.).

A discussion of Baker's work on the drying of chemical substances is illuminating, since it refers to experiments performed in the school laboratory. He showed that dry oxygen will not support the combustion of dry carbon or dry sulphur. Carefully prepared calcium oxide and ammonium chloride, after drying for seventeen days, liberated no ammonia, when mixed and heated. Details of Baker's investigations could be extended. It has been shown by others that pure nitric acid, free from water and oxides of nitrogen, does not attack pure copper, silver or mercury. Pure zinc is not attacked by pure sulphuric acid or pure hydrochloric acid.

Many other topics should also receive attention; e.g. amorphous carbon probably consists of very minute crystals; the luminosity of a Bunsen burner flame disappears not only when enough air is admitted through the air-boles, but also if other gases are admitted; solution may be chemical or physical, and it is often difficult to distinguish between the two.

Chemists believe that the law of conservation of mass must now be modified, since matter can be converted into energy. The precise reactions occurring when iron rusts, when magnesium is heated in a crucible or test-tube, and when copper reacts with concentrated

sulphuric acid are not clearly understood. The precise formulae of bleaching powder and Prussian blue are not known.

Discussion may centre round catalytic action in chemical reactions. Reference should certainly be made to the newer researches on the syntheses of alcohols and other solvents; the hydrogenation of coal and the manufacture of lead tetra-ethyl motor-spirit; the synthesis of rubber, nylon and plastics; the extraction of magnesium and bromine from sea-water and lakes; and the manufacture of sulphuric acid from calcium sulphate.

The treatment of these subjects shows that Chemistry is still developing. Students in senior classes realize that elementary textbooks are written in a simplified form for the benefit of the non-specialist, and that in later years these general principles and simple facts need to be extended and modified.

CHAPTER X

The Varied Influences of Language on the Learning of Chemistry

Using scientific language

When modern Science began to develop in the seventeenth century, men of Science realized the need for a specialized language, so that they might express their views clearly and define their ideas precisely. The Royal Society was founded in 1660 with:—

‘A constant resolution . . . to reject all amplifications, digressions, and swellings of style. . . . They have exacted from their members a close, naked, natural way of speaking and bringing all things as near the mathematical plainness as they can.’

Lavoisier’s influence on the systematic naming of elements was a further advance when, for example, the terms phlogiston and dephlogisticated air became obsolete and the names hydrogen and oxygen were introduced.

In 1918 the Report on Natural Science in Education pointed out:—

‘All through the Science course, the greatest care should be taken to insist on the accurate use of the English language. The longer the time given to Science, the greater becomes the responsibility of the teacher in this matter.’ ‘If he (the pupil) has been doing an experiment he should at least be able to describe what he did and what he saw in simple and comprehensive language, in the plain English of educated people. The conventional jargon of laboratories, which is far too common in much that is written in pure and applied Science, is quite out of place in schools. The Science master cannot be allowed to repudiate responsibility for the English in which the work of his class is written.’

It is a common complaint of Chemistry teachers that during the early years the correction of note-books means a correction of mistakes in English rather than of fact. In Chemistry the written work is sometimes marred by illegibility, untidiness and bad spelling, in addition to lack of effective description in simple terms. This is partly due to the limitations of the laboratory. Notes must be written while

the pupil is surrounded by apparatus. Observations have to be made and impressions recorded at the same time. These distractions handicap the pupil in acquiring the habit of writing thoughtful English, and of doing well-arranged written work. It is often advisable, therefore, to allow pupils to make rough notes in pencil during the course of the experiment, and to rewrite and amplify these for homework. Alternatively, full notes can be written out directly after the experiment has been completed and the benches cleared, or by using side-benches, another laboratory or a classroom. It is essential, however, that some notes should be made as the experiment proceeds.

Scientific words

The problem of the proper use of the specialized language of Science must be seriously considered if laboratory work is to be successful. There is no doubt that Chemistry has a special vocabulary of its own. Ordinary language differs from it in containing innumerable vigorous and lively words. The meaning attached to these varies slightly and indefinitely with the experience of the user. Very often these words evoke images coloured by personal experience. They describe emotional states, they appeal to the varying interest of individual feeling or emotion, and because of this they arouse varying reactions. In conversation and literature a word is not necessarily the symbol of a definite circumscribed idea; it often covers, within fairly definite limits, a wide variety of concepts. Scientific words are more precise, and are usually associated with a definite idea or object. They ought to convey no other meaning than the one intended, so that they do not give rise to a popular conception differing from the stricter scientific one. Scientific language attempts to obtain a definite nomenclature, almost as definite as a formula. Because the meanings of the words for these purposes should be limited, Greek and Latin (no longer living languages) are very suitable for the construction of scientific terms. There are historical reasons for this use of Greek and Latin, and although, as a source from which to derive a scientific nomenclature, they are by no means perfect, yet they offer certain definite advantages. Mistaken nomenclature is less serious when derived from a dead language; for example, 'oxygen' reminds the pupil less of its mistaken association with acids than does the German 'Sauerstoff'.

Thus, words used in Science and derived from Greek and Latin are more likely to possess an exact meaning, free from the misleading interpretations of popular thought which might be associated with words of one's own country. The language of Chemistry should have no association with personal prejudices or the emotions. The terms used can be precise, the names of numerous compounds can be easily constructed from the same root, and by adding suffixes and prefixes, which do not vary in meaning, the concept can be limited or extended precisely. In addition, most countries use the same terminology and a scientific language, which should be intelligible to all nations. Thus, the advantages of a special scientific language are that great exactness in nomenclature can be obtained, and special apparatus, chemicals and reactions can be described with precision. These words should be used in technical discussions where it is desired to name a process rather than to describe it. The teacher should accept the principle that clear logical thinking necessitates the correct use of words. Since the pupil reasons by the use of words, he must always write exactly what he means; and his accounts should be so precise that there is no doubt of his meaning.

Scientific facts known to beginners

Much interesting work has been done on the content of a child's mind. An American investigator found that the concrete experience of children entering primary schools differed very greatly. Of town children, 6 to 7 years of age, entering school

- 54 per cent. knew nothing of sheep;
- 61 " " had never seen a potato growing;
- 35 " " did not know what clouds are;
- 35 " " did not know what a circle is.

Similar results would no doubt be obtained if pupils beginning Chemistry were tested.

An analysis of results collected by the writer supports this. Sets of replies were obtained each year from ninety-three boys and girls, aged 11 to 13. Twenty-three had previously been taught elementary Science, and a few of these even introduced formulae in their replies.

The following replies show that care must be taken to determine what difficulties in language face the beginner. The numbers in

brackets show the average numbers of answers given by the pupils.

- (a) Mercury is a liquid (73), a solid (15), a gas (2).
- (b) Air is one substance (2), or more than one (90).
- (c) If sugar is put into tea and stirred some disappears. What happens to the sugar? Dissolved (82). Melted (6).
- (d) If sand is put into water and it is warmed, the sand will not disappear. What word is used here? Insoluble (9). Remainder gave wrong answers.

- (e) Give another word for combustion. Burning (9).
- (f) What is the lightest gas known? Hydrogen (14).
- (g) Name an acid you know. Sulphuric acid (18). Carbolic acid (15). Nitric acid (10). Hydrochloric acid (8). Tartaric acid (2); and a few other acids occurred once.

Such tests, even on a small scale, indicate where difficulties are likely to occur. Suitable tests should be given each year to obtain some idea of the pupils' knowledge of facts and to determine what words or phrases may be merely mentioned, and which must be explained in detail. The facts known to the child will vary with home background, sex, type of school and locality. The difficulties will be greater in schools which draw their pupils from a wide area. Some pupils from primary schools (aged 11 to 13) may come with a sound background of scientific facts, but, on the other hand, others will have been taught by inappropriate methods, the effects of which will have to be remedied. Consequently, a teacher often begins to teach Chemistry to pupils differing widely in experience and knowledge, and it can therefore be seen how essential it is for him to have some idea of the pupils' capacities.

Scientific words in periodicals and newspapers

After a few months' study of Chemistry, the pupil becomes familiar with many new terms, and if he has been carefully taught he should appreciate their true meaning. If the general principles discussed in this chapter are borne in mind, the right approach to the individual problems of outside reading, note-taking, and the writing of clear and concise English can then be made.

The training in language appreciation should enable pupils to read a newspaper article or a popular science book with intelligence.

This means that preparation would be made in Science lessons for recreative hours in the years to come. Our pupils should be so trained that they can read and appreciate news of recent research work, and it is most helpful to refer to this in simple language in class. The pupils should, if they wish, be able to take up a craft which includes applications of Science, and they should be able to understand the instructions given in simple and popular practical books.

In most countries, little research appears to have been done on the proportion of scientific words appearing in periodicals and newspapers. From data obtained from American newspapers, however, it is found that the addition of one thousand new words to a child's vocabulary does not greatly add to his ability to read the daily press. It was found that out of 271,663 words occurring in six American newspapers 12,802 were scientific. As a percentage, the number of scientific words was 4.2 of the total. In contrast with this there were only 3.6 per cent. of uncommon words, and 32.7 per cent. of these were scientific. The number of scientific words occurring in representative American magazines has been counted, and it is found that most of them are biological rather than chemical. When chemical words occur they are often from the vocabulary of advanced rather than elementary Chemistry. At present most of these words are connected with atomic structure and biochemistry.

It is thus seen that a training in the specialized language of Science is an important part of each pupil's education, and great care should be taken to ensure that the many difficulties encountered are effectively removed or minimized by thoughtful teaching methods.

Learning chemical names

In his first few Chemistry lessons many unfamiliar substances are introduced to the pupil, and the teacher must be careful not to fall into the mistake of thinking that the mere names recall as many properties to the pupils as they do to more mature minds. The beginner's facts are not only few but they are scattered. Some few pupils remember the names of chemicals after once using them, but more often it is necessary to mention the names and properties time after time, as suitable occasions arise. It is helpful, after using groups of chemicals of similar appearance such as potassium chlorate, potas-

sium nitrate and potassium carbonate, or carbon, manganese dioxide, and cupric oxide, to spend a few minutes in pointing out their essential differences. A practical revision test might include the action of heat, concentrated hydrochloric acid, dilute sulphuric acid and litharge (lead monoxide) on each of these substances. Alternatively, the teacher might demonstrate the danger of confusing carbon and manganese dioxide by beating *very small* portions of each with potassium chlorate. It is only by frequent reference to old material in a new way that the names and properties of such compounds are understood and remembered by the pupil.

Again, mistakes are often due to similarity in spelling or pronunciation of chemical names. Examples are manganese and magnesium; sulphite, sulphide and sulphate; chlorate and chloride; nitrite, nitride and nitrate; hydrogen and nitrogen. These substances have very different properties, and often when the pupil appears to be making a ridiculous statement, he is merely confused by the spelling or pronunciation. This accounts for statements such as: 'the air contains 80 per cent. of hydrogen' and 'potassium chlorate is heated with $\frac{1}{2}$ its weight of magnesium dioxide to prepare oxygen'. It is important to stress the spelling of such words by printing them on the blackboard and, if possible, to refer to some application or characteristic of each chemical.

For instance, it is helpful to connect potassium nitrate with gunpowder and meat preservation; magnesium sulphate with Epsom salts; the rusting of iron with galvanized iron and the nickel and chromium plating on a bicycle; and calcium carbonate with egg-shells and marble. Other compounds, such as mercuric oxide and lead oxide, can be mentioned when discussing the historical work of Rey, Priestley and Lavoisier.

Here it should be mentioned that if the historical and heuristic methods are carried out in their entirety, a substance is often given a name which must later be altered. Oxygen is first known as 'active air' or 'active gas', or 'fire air'; carbon dioxide as 'fixed air', 'chalk air', or 'soda air'; and hydrogen as 'inflammable air'. Not only do these alternative names add to the amount of memory work, but they introduce other difficulties. A pupil may be inclined to think that carbon dioxide is prepared from chalk alone, or that hydrogen is the only inflammable gas. In consequence, it may be better to give the

chemical its correct name from the beginning. Unfortunately, some common substances have more than one name. It is helpful to write on the blackboard all the names of such a substance when it is first mentioned. Thus, when potassium nitrate is first used, the names potassium nitrate, saltpetre and nitre are written on the blackboard and bracketed together. A common substance such as baking-soda has three chemical names, sodium hydrogen carbonate, sodium acid carbonate, and sodium bicarbonate. It might be noted here that sodium hydroxide is also known as caustic soda and sodium hydrate. The latter is, unfortunately, often sand-blasted on reagent bottles and printed on labels, and therefore must be mentioned; but it is entirely wrong, and so should never again be used by the teacher. Further, the Greek prefixes, mono-, di-, tri-, and the Latin uni-, bi- and ter- are usually interchangeable (although dicarbonate and bi-oxide are never used), and the young pupil has to learn both systems. The general tendency, however, is to use Greek, and a word such as divalent is often used when bivalent would be more correct by derivation.

It is extremely difficult for a teacher to explain why some terms are preferable to others, and this aspect is one that needs his close attention. It will simplify matters for the pupils if a definite system for naming chemicals is used in the lower classes. Later, however, the pupils become familiar with synonymous words.

The correct naming of apparatus is another difficulty encountered by many young pupils. They resort to the use of names such as bowl, vessel, jar and bottle as substitutes for the correct names. The writer has known a flask referred to as 'a globe tube', and a gas-jar lid called 'a circular, flat piece of plain glass'. Crucibles are frequently confused with evaporating basins, and crucible tongs are called forceps or pincers. If the teacher finds that such difficulties are likely to arise, incidental teaching is not enough, and the names must be definitely taught.

Suitable tests should be given at intervals to find out the sort of difficulties caused by technical language, for it must be realized that, if an unfamiliar or abstract term cannot be connected with a known one, or with a concrete experience, mental dissatisfaction soon arises. The Chemistry course must therefore cultivate a gradual growth of ideas, and the pupils' own experience must be the starting-point. The

young teacher may soon discover that the pupil is experiencing difficulty not only in understanding, but also in learning, this specialized language. A minimum number of carefully graded technical words should be introduced, but only when they become really necessary.

Teachers themselves differ in their views on the correct use of quite simple terms. Thus, *millilitre* (ml.) is certainly being increasingly used instead of *cubic centimetre* (c.c.), but there is little uniformity in the description of collecting gases by displacement of air, depending on their densities. Authors describe the collection of gases with a greater density than air as by:—

(i) downward displacement, (ii) upward displacement, (iii) downwards by the displacement of air, (iv) by the displacement of air upwards, (v) downward delivery. It almost appears advisable to state that the gas is denser than air and to give a labelled sketch of the apparatus used.

If ordinary words express an idea clearly, they should be used. In any case some of the methods used effectively in the teaching of modern languages, including vocabulary-selection, should be adopted. In the first year it is unnecessary to use words such as allotrope—white and red phosphorus suffice. Later, it is essential in the interests of both economy and precision to know the meanings of words, as far as they apply, such as oxidation, reduction, liquefaction, deliquescence, and catalysis. The teacher himself, at this early stage, must be careful to explain the meaning of the terms he uses. He may unconsciously mention words beyond the pupil's range of knowledge, such as effervescence, combustion, stable, reaction, ore, mineral, qualitative and quantitative. Many of these semi-technical words are rarely used in ordinary conversation. It is not easy even for adults to explain the difference between melt and dissolve, pure and impure.

Research shows that a school pupil may be expected to learn between 800 and 1,000 new words yearly in a foreign language, and special attention is accordingly given to learning the new vocabulary. In Chemistry as large a number of words and definitions is expected to be learnt, often, however, by incidental hearing and reading rather than by specific teaching and learning.

Few definitions should be given in the early work, and all terms

must be used with care and exactness. The young teacher must ask himself many questions when arranging the laboratory work. How much of the vocabulary does the pupil really understand when he is carrying out laboratory instructions? Do certain words convey an exact meaning to him? How much of his normal vocabulary will be of use to him in the laboratory? There are occasions when the pupil receives practically no benefit, because the problem is approached from a mature point of view in language far above his head. He struggles with technical phrases, and often the object of the experiment is obscured completely by the unfamiliar terminology. This the young teacher will soon discover for himself, and he must be particularly careful to avoid using the chemical jargon familiar to him from his university reading. Unless he attempts to grade his language and explain and define his terms with care, pupils will fail to understand him and therefore miss many points. A few pupils may ask for explanations, but more often the teacher will have to rely on his own observations to discover if he is adapting his language satisfactorily to the standard of the pupils.

When the pupils have to answer written questions, similar difficulties arise. In one examination when young pupils were asked to 'enumerate the properties of carbon dioxide, etc.' more than half the form were unable to tackle the question because they did not understand the meaning of 'enumerate'. A boy may understand 'change', but not 'reaction'; he may remember that 'common salt colours the flame a golden yellow', but not that 'sodium chloride is volatile in the flame'; he knows that sodium hydroxide absorbs water, but does not understand 'deliquescent' and 'hygroscopic'.

Definitions and terms.—Most pupils are satisfied with the exactness of the few definitions they are required to learn in the Chemistry course. As the course proceeds, however, a few of the more thoughtful pupils question the accuracy of the wording of certain definitions. For example, a saturated solution is often defined as 'a solution which will dissolve no more solute at a given temperature'; later, a super-saturated solution is prepared, and the earlier definition is questioned. A more satisfactory way of defining a saturated solution is 'a solution that, at a given temperature, neither dissolves nor deposits any of the solute with which it is in contact', or 'a solution

which contains all the dissolved solute that it can acquire from the undissolved solute at the temperature in question'.

Again, the intelligent pupil queries the truth of certain definitions in the light of modern research. For these pupils the definition of an element, 'a substance which cannot be split up into simpler substances', will have to be amended by substituting 'an element is a substance which cannot be split up by ordinary chemical methods into simpler substances', or 'a substance all of whose atoms have the same nuclear charge'. The latter definition will satisfy advanced students and will avoid trouble when dealing with isotopes.

Another interesting point which a Chemistry teacher will encounter is the occasional lack of agreement in the meaning of common terms. For example, pupils may use 'strong', meaning 'active', in describing the tendency of an element such as oxygen to enter readily into combination with other elements; or to mean 'stable' in stating that copper oxide will not decompose. 'Strong acid' and 'the strong solution of an acid' are often used indiscriminately. The use of 'strong' in the first two cases must be definitely forbidden, and in the last example it is better to use 'concentrated' when referring to a solution.

The following have the same meaning:—water of hydration and water of crystallization; laws of constant composition and fixed proportions; hydrochloric acid gas and hydrogen chloride; thiocyanate and the older word sulphocyanide.

A mistaken tendency is to explain a phenomenon by means of a term. A pupil should not think that the term 'catalysis' *explains* the action of manganese dioxide in accelerating the evolution of oxygen from the 'oxygen mixture': it classifies the reaction. And it must be made clear that the so-called explanations of Chemistry usually get no further than describing the observed facts in lucid terms. In this example, the formation of intermediate compounds suggested by one theory gives a partial explanation, and much research work is now directed towards finding both why and how such catalytic reactions occur.

Intelligent pupils often experience difficulty in the comparison of chemical and physical changes, owing to the lack of clear-cut distinction, and the teacher must be prepared for some awkward questions. Pupils accept the fact that a chemical change results in the

formation of a new substance with new properties, but the statement that 'heat and light are usually absorbed or evolved during a chemical change' may lead to the mention of concentrated sulphuric acid and water, or of common salt and snow. The teacher must then point out that the statement includes the word *usually*, and that it does not state that heat changes *never* accompany a physical change. Similarly, it must be pointed out that there are reservations to the statement that a chemical change cannot easily be reversed: the pupil may easily get confused when he tries to compare the changes occurring when, for instance, mercuric oxide and iodine are each heated, or solutions of nitre and of ammonia are prepared. The usual standard illustrations of chemical and physical changes are satisfactory, but much help and guidance from the teacher will be needed in the selection of further examples.

An example of a general principle must be carefully described and thoroughly understood, while the principle itself must be stated clearly and concisely.

Training in note-making

Practical notes are written up in many ways, and it would be wrong to lay down any rule on the subject, since the conditions in school laboratories are so varied. Although it is preferable for the pupil to enter up his notes in the laboratory as the experiment proceeds, it is impossible in many schools owing to lack of space and time. Under these conditions, rough notes should be taken in the laboratory and a careful and precise account of the observations and conclusions written later. In the later years of the Science course, however, the whole of the theoretical and practical work should be written up immediately in the lecture-room and laboratory respectively.

Teachers have their own individual preferences in the matter of order and scope of sub-titles. Some prefer exact divisions under the headings of 'experiment', 'method', 'observation', and 'conclusions', or purpose, material, apparatus, procedure, results and conclusions. Others try to avoid the repetition, which so often occurs under the above system, by encouraging pupils to write original notes. It is important, whatever the system used, to train the pupil in note-making. This can be done either by putting skeleton notes on the blackboard for the first few lessons, or by going through the work

carefully and telling the pupil exactly what is required. While some teachers encourage the use of the personal pronoun in laboratory notes, believing that in this way the experiment makes a personal appeal, others expect the imperative to be used, and state that on no account must 'I' or 'we' be found in the pupil's note-book. The use of the personal pronouns may be allowed in the first year only if the teacher is convinced of its usefulness. Later, the imperative should be discouraged, and definitely forbidden in the middle and higher classes, since careless and lazy pupils do not describe the work in their own language, but merely copy down the instructions mechanically. Modern scientific literature is written in the past passive tense, and the writer recommends that this style should be cultivated in school note-books.

Many pupils find it extremely difficult to describe an experiment in simple and straightforward language; they use long and complicated sentences in trying to describe disconnected facts; they use abbreviations wrongly. These faults must be corrected. The first essential is that short sentences must be used, each describing one fact. It is not until the pupil is more advanced that he should be allowed to combine these sentences to describe two or more related facts. Often, the correct use of scientific phrases does not come naturally, so by reading a good pupil's account, a weaker pupil can realize the standard which he must try to attain. The pupil must be trained to concentrate on describing clearly and concisely the precise sequence of events, and in writing out correct inferences from these.

Many educationalists doubt whether pupils derive much benefit from writing up at length fair copies of their rough notes. It is the author's view that some method should be devised to reduce this re-writing of notes. It does not always help pupils to retain facts and principles, and conscientious teachers are given far too much correction work. Some pupils like writing out long notes and derive benefit from such work. Others rarely consult their own notes and prefer to rely on their text-books. Some record of an experiment is clearly necessary, since a note-book shows how a pupil keeps his records and works out his conclusions. Further, a continuous account of a year's work is thus made available and the pupil can be shown that he is carrying out the methods of the man of Science. Much more variety, however, ought to be expected, and, with juniors, cuttings from

newspapers and magazines, illustrations, accounts of their own observations out of school or of their own experiments, and notes from reference books might be allowed.

Another method is to use a laboratory note-book specially designed to give the pupil training in the correct use of words, the understanding of definitions and the drawing of apparatus. Such a note-book avoids excessive writing of routine notes, and instead emphasis is laid on learning-exercises and suitable self-testing questions. In the U.S.A., work-books and laboratory manuals are used as guides to obviate unnecessary note-making. Such books, devised and written by small groups of expert teachers, are accepted by many educational experts as providing a scheme of work which cannot be so efficiently organized by the average class teacher.

An original method is used by one author, who states that words which are unfamiliar to the average beginner should not always be avoided. It is inadvisable to try to avoid them by circumlocution, as the precise significance of these words must soon be learned. Since Chemistry should contribute to the widening of the pupils' powers of expression, he gives at the end of each chapter lists of words which have to be looked up in the dictionary and learnt—words such as corrosion, empirical, incandescence and deliquescence. It is not too much to expect of pupils, for the amount of dictionary work is much less than that involved in the preparation of ten lines of a Latin set-book.

Symbols, formulae and equations are used by the Science specialist as part of his professional training. Much of his work will be written in an abbreviated and summarized form, but only reasonable abbreviations should be allowed; hybrids of the type 'Fe acetate' or 'NaSO₄' (*sic*) should be definitely excluded. This method of writing, however, must not be over-emphasized, and some attention should be given to the technique of composition. The complaints from both the Education and Science departments of universities that their Science students are unable to write good essays must be considered. The most constructive suggestion is to expect definite essay writing, from advanced students, on suitable subjects of historical or descriptive interest. It is usually advisable for the subject-matter, forming the basis of the essay, to be extracted by the pupils from advanced textbooks. These essays should usually be marked by the Chemistry

teacher, but occasionally the language specialist should be asked to assess their merits solely as compositions. The pupil will benefit by criticisms from both teachers, and will realize that language is an instrument to be used with care and precision in every school subject. Every teacher is a teacher of language.

Thus it is clear that, at every stage of a pupil's development, the teacher must consider the best methods of securing the maximum benefit from written work. Why should a pupil keep a detailed account?—as a mere record of his practical and theoretical studies, or so that the teacher can assess the rate of progress in understanding, observation and deduction? Should a complete account be written up, or are summaries to be allowed? Will the pupil's notebook be used later for revision, or will he discard it in preference for a text-book? How far might labelled diagrams help to avoid excessive note-taking? All these questions must be considered carefully by the teacher of Chemistry.

Extracts from pupils' note-books. — The following extracts may lack precision, but they show keen observation and a power of vivid description rarely found in junior note-books. 'Iron is a gun-metal colour, with microscopic specks of silver shining through. On adding sulphur it turns a slate colour. . . . On heating iron and sulphur it turns an amber hue, and an apple-green vapour is evolved. A liquid jumps up the test-tube like wine, and black grains can be seen. . . . On cooling, the substance passes through various colours. The side of the test-tube is finally covered with a mottled, coloured liquid, and the compound remaining is a grey ash.' Such writing should be encouraged when it is based on really careful observation. With practice, scientific terms may be substituted for the less exact ones, and eventually the clear lucid style, so necessary in scientific writing, will be developed.

The difference between the dull and the intelligent pupil is very marked. The former requires continual attention to help him to avoid defects in spelling, lucidity and subject-matter, while the latter produces notes of a most readable and satisfactory nature, such as the following, written by a boy who had studied Chemistry for only eight weeks: 'Concentrated nitric acid is brown owing to some nitrogen peroxide (NO_2) dissolving in the acid vapour in the preparation

of the acid. These fumes are formed owing to the decomposition of nitric acid by the high temperature of the reaction.'

The marking of Chemistry note-books

An examination of the written work gives the teacher a fair idea of the progress of his pupils. The errors found in their notes will indicate which parts of the course were not understood, and which experiments were partial failures. A careful record of all types of errors should be kept. It will prove invaluable when preparing future lessons.

The usual laborious method of crossing out faults and writing the corrections in the margin of the pupil's note-book can be improved upon by substituting one which is of greater educational value. A system of notation can be used which refers to the most frequent kinds of errors. In this way, the mistake and its nature are indicated, but the actual correction is not made by the teacher. Different notations may be used, but it is advisable for the English, General Science, Physics, Biology and Chemistry teachers to use similar methods in the correction of pupils' note-books—often a very difficult matter to arrange, but well worth attempting.

In the elementary General Science course, early training can be given by the use of a simplified system such as the following:—F, mistake of fact; Gr. or G, mistake in grammar; Sp. or S, spelling error; Ill., illustrate by sketch or diagram.

In later years the following code of symbols is suggested for marking; and each pupil should copy it out inside the front cover of his note-book.

C? or C, What do you conclude from this statement?

D, Give more details.

E, Give equation.

F, Mistake of fact.

G, Mistake of grammar.

Ill., Illustrate by sketch or diagram.

L, Look up in Chemistry library.

M, Previous mistake not corrected.

R, Refer to me (i.e. teacher).

S, Spelling mistake.

W? or W, Why do you make this statement?

Spelling mistakes should be written out three times, and other corrections should be put in the margin opposite the error, or at the end of the work. This method of correcting saves the teacher's time, and has a distinct educational value in that it enables the pupil to correct his own mistakes and search for the right answers from various sources. Moreover, the bright boy, who is often neglected for his less able classmates, is given special scope, as the lettering in the margin of his note-book indicates which parts of the subject he can profitably pursue further.

Errors in the pupils' note-books. Mistakes in spelling, grammar and lack of detail.—The corrections referred to under the headings 'G' (grammar), 'M' (previous mistake) and 'S' (spelling mistake) are looked up and corrected by the pupils themselves. Spelling mistakes may be avoided to some extent by writing the word on the black-board and pointing out its structure, so that the spelling of the word may be learnt when it is first used. A chart containing the difficult words encountered each year may be posted on the notice-board. Further, a list of words and terms which are difficult to spell might be kept by the pupil at the end of his note-book so that he may learn how to spell them. Words such as evaporate, phosphorus, hydrochloric, catalyst, alkali, potassium, paraffin, aluminium and ammonium always cause trouble.

Mistakes are often due to carelessness or slackness. Thus, 'alcoholide' occasionally occurs for 'alkali', 'nitrogen' for 'hydrogen', 'chloride' for 'chlorate', and 'hydrochloride' for 'hydroxide'. In some cases, errors of this kind may be due to hardness of hearing. In any case, it is advisable to write a new word of this type on the black-board.

Under 'D' are included mistakes such as the following: 'A glowing splint burst into flame when placed in the mouth of the test-tube in which copper nitrate was heated. This shows that there was something in the nitrogen peroxide which supported combustion, this being oxygen.' The correction enables the teacher to find out if the pupil has been unable to express clearly that oxygen is evolved along with the nitrogen dioxide or if he considers that the re-kindling of the splint was due to the combined oxygen.

Another pupil stated that 'Sulphuric acid is the hottest of the

dilute acids', referring to the amount of heat evolved when the concentrated acids were poured into cold water.

Statements such as, 'Oxides which are not metals mix with water and form acids', 'Concentrated hydrochloric acid and potassium chlorate turn yellowish green', 'When red-lead is heated, it evolves oxygen' become more explicit when further details are supplied. The pupil must be encouraged to supply, or ask for, these details.

Mistakes of fact.—'F' is used to denote errors such as 'white' for 'colourless', 'melt' for 'dissolve', and other obvious inaccuracies.

The following extracts show how the function of an experiment is misinterpreted, and how pupils find difficulty in describing their observations.

'Air was passed through copper filings where all the oxygen was consumed.' ('Removed by oxidation' should have been written.)

'A strong gas was given off.' (Meaning a gas with a distinctive smell.)

'Sulphur is a non-dissolvent in water.' (Insoluble.)

'Using a burette for the neutralization of the acid and alkali, it is found that the formula for common salt is 20 c.c. of sodium hydroxide and 17.5 c.c. of dilute hydrochloric acid.'

'I procured an unbreakable test-tube.'

'Oxygen supports the theory of combustion.'

'Burn phosphorus in a jar of oxygen, put litmus in, it turns red, therefore phosphorus is an acid.'

'Ammonia (ammonium chloride) is said to be sublime; on heating a mixture of it and sodium (sodium chloride) the latter is left behind.'

'When sodium is dropped on to water it lights and burns with a yellow flame.'

'Add potassium to dilute nitric acid to form potassium nitrate.'

'Phosphorus is kept in a bottle of water because water is colder than air.'

'Sodium is kept in oil because it loses its strength', or 'it goes stale', or 'it rots away', or 'the air would perish it'.

'Equal weights of the three allotropes of carbon form the same weight of carbon dioxide.' (Example of loose phrasing.)

'Remove the iron from iron chloride by using a magnet.'

'The presence of sodium in sodium nitrate can be shown by dropping the latter in water, when it evolves hydrogen.'

'Sodium hydroxide becomes moist when brought into air, and turns into water.'

A remark such as the following can be avoided if the teacher himself is careful to use the correct terms in describing the experiment. 'The nitric acid fumes find it too hot for them in the retort so they move to the cooler parts of the receiver.'

The following extracts show carelessness and lack of attention in class. In correcting these a pupil will probably obtain most benefit by asking one of the better pupils for the necessary information.

'Then came the Iatro chemists, who made Paracelsus, which was considering and purifying drugs.'

'Egypt was called the "Black Land" because the Nile over-flowed, and it was called the "Black Art" because nobody knew why it had overflowed.'

Results and conclusions (C).—In a quantitative analysis the numerical results complete the experiment, and whenever possible the practical result should be compared with the value obtained from theoretical considerations. Valuable exercises are provided by discussing the reasons for any variation between the two. The formulation of conclusions from such systematic work tests the best of pupils.

It is important that lists of numerical results, such as titrations or weighings, should be written under one another in a systematic and complete form. This method is neat and clear, and enables the teacher to check the pupil's working with ease.

At the end of a series of experiments, it is expected that most pupils will arrive at a conclusion, such as 'concentrated hydrochloric acid evolves chlorine when heated with oxidizing agents', and 'all ammonium salts evolve ammonia when heated with an alkali'. It must be admitted that to obtain such conclusions, or to summarize the facts obtained from the experiment, is often extremely difficult, but it is a part of Chemistry teaching that should never be neglected.

Reference to library (L), and further details (D).—By placing 'L' in the pupil's note-book, a teacher can indicate that more details might be obtained from the school or public libraries. This method encourages the development of a wider study of Science, and is of especial benefit to clever pupils. Thus, 'L' in the note-book containing 'When sulphur dioxide was shaken up with water it formed sulphurous acid.

This acid has never been isolated so we do not bother much about it as it is very unstable' brought the following amplification: 'Sulphur dioxide dissolves in water, and it is then of great importance in commerce for bleaching, disinfectants, and in the manufacture of the important acid, sulphuric acid.'

Each pupil should, if possible, be given training in the use of indexes of the more specifically useful books, and advice on other books which may contain more general information. A pupil's note-book often indicates in what direction his interests lie, and opportunity should be taken to cultivate this particular bent.

Other references.—Further quotations from pupils' note-books illustrate the application of the symbols 'E' and 'W'. One boy, after four weeks' Chemistry, wrote, 'Dilute the acid by means of water to the scale of dilution required. Pour a little of the dilute nitric acid on to a few crystals of sodium carbonate decahydrate, known as washing soda to people not concerned with Chemistry.' A 'W' against this remark brought the answer: 'This makes soda different from ordinary sodium carbonate because it has ten molecules of water combined with it.'

Statements such as the following are clarified by using the notation sign 'W'—Why do you make this statement?

'The fumes from the solution smell like a very familiar smell.'

'In dilute sulphuric acid, the zinc goes very porous, and out of it escapes the gas.'

'Hydrochloric acid is weaker than sulphuric acid.'

Some pupils, without encouragement, learn to use formulae and equations early in the course. Symbols are not normally used until the later years, but the enthusiastic learner, if this is considered advisable, can be kept up to the standard he has set himself. Abbreviated words and the wrong use of symbols must not be allowed. Thus, a boy who attempts to use S.H. for sodium hydroxide, or builds up the following equation,



should immediately be corrected.

The account which is too long and irrelevant must be discouraged, and a clear, precise style cultivated. Unnecessary repetition must also be avoided. It is encouraging to find a pupil who, after describing the

action of dilute sulphuric acid on magnesium, forming magnesium sulphate and hydrogen, states: 'The method used for the action of this acid on magnesium carbonate is nearly the same as in the former experiment, so it will only be described in brief.' Concentrating on differences, he avoided all repetition.

The teacher ought to keep a record of mistakes made by his pupils and classify them. This will enable him to anticipate such mistakes, although words such as 'phosphorus', 'nitrogen', 'diamond', 'desiccator' and 'laboratory' will often be misspelt, bromine will be described as a gas, phosphorus as a metal, lead sulphate as being soluble in water, and iron alum as containing aluminium.

From time to time written work should be set either on topics having a wider scope than the usual school work, or on revision problems requiring solution by careful reasoning from the facts obtained in the laboratory. Excellent training is derived from exercises necessitating the use of encyclopaedias and the indexes of comprehensive reference books. The information thus gained has to be sifted, irrelevant subject-matter discarded, and the useful points systematized and incorporated in the pupils' written account.

CHAPTER XI

The Use of Diagrams, Charts and Other Visual Aids

Diagrams and drawings in the laboratory note-book

The teaching of the proper use of diagrams and drawings by juniors presents real difficulty. Many pupils who are good at practical work hand in disappointing descriptions of their observations and results. Their note-books do not give a true indication of their manipulative skill, neither are they of any use for revision purposes. These pupils in particular must be taught to realize the importance of accurate and clear drawings, around which so much of the descriptive work may be centred.

A few pupils find it very difficult to draw apparatus at all, while others, with artistic ability, have to be discouraged from making pictures instead of diagrams. Pupils who experience difficulty in drawing the different parts of apparatus to scale must be trained to compare the size and positions of all parts of the apparatus, even if it becomes necessary to measure the different parts.

A pupil might be given further help by asking him to point out the parts of the apparatus represented by particular lines in his drawing. It is especially necessary in the early stages for apparatus to be shown in the drawing in exactly the same order as it is arranged on the bench, i.e. the sink should be on the right in distillation in both sketch and in the actual apparatus set up by the class. If a pupil cannot make a drawing of value after reasonable training, he should be allowed to omit drawings and to describe the apparatus in words. This is rarely necessary, but it emphasizes the fact that the drawing is only part of the description.

It is worth while devoting time at the beginning of the course to discussion of the most effective methods of representing apparatus on paper. In this way, all types of pupil are given opportunities of learning the method recommended by the teacher. Apparatus must be drawn in proportion, and the essential features of each component must be clearly shown. Neatness, clearness and economy of time in

drawing must be stressed. Good examples of diagrams should be exhibited on the laboratory notice-board so that the pupil is constantly reminded of the method required.

Comparison of the methods used in text-books. — An examination of the drawings of apparatus found in text-books shows very clearly that there is no strict adherence to a uniform plan. The worst features of poor sketches might be pointed out to the pupils. In some drawings there is excessive shading, which often obscures some of the main details of the apparatus, so that the drawings become too indistinct to be of much value. Other drawings are so elaborate that an expert draughtsman must have spent several hours in their preparation. It would be a clear waste of time for a learner to imitate such methods. In some text-books, various drawing devices are suggested: glass tubing, retort stands and tripods are represented by single lines, and 'cutaways' in pneumatic troughs show hidden parts of the apparatus. Whilst many sketches are in perspective, some give sketches partly in perspective and partly in section. In some drawings the apparatus is not labelled, while in others labels are there but are not referred to in the text. Few books are illustrated by clear, simple, labelled, sectional drawings of the type recommended in this chapter.

It might be noted that photographs illustrating industrial Chemistry are becoming more popular in school text-books. The principle is an admirable one, if suitable photographs can be found and if these are accompanied by labelled sketches of the parts of the industrial plant most difficult to understand.

The pupil must realize, however, that his drawings, diagrams and charts serve a purpose rather different from those included in text-books. He is allowed the use of legitimate conventions, notations and symbols in order to avoid unnecessary repetition, and his drawings should emphasize those parts of the apparatus which are encountered for the first time. Thus, when the pupil first sees a Kipp's apparatus, a complete sketch should be given, but this is not necessary every time this apparatus is used subsequently. A pupil cannot be expected to give a detailed sketch of a blast-furnace or gas-works. He must represent the various parts by circles, rectangles or other simple shapes, and refer to lettered parts of the diagram in his notes.

Sometimes the diagram may represent an aerial view of part of a factory, but usually it is a conventional diagram in sectional form.

The value of drawings.—It is generally agreed that sketches and diagrams are necessary in Chemistry note-books, for at each stage in the pupil's training they serve a definite purpose. Sketches are very often as important in chemical descriptions as figures are in geometrical propositions.

Most examining bodies ask for sketches, and some state that elaborate drawings are not required. Unfortunately, they are not all as definite as one examining body which states that 'The answers should be concisely worded and as short as is consistent with clearness and completeness. Large, clear and accurate drawings should be added whenever they make the answer easier to understand. A very high value is attached to drawings which are the result of careful observation.'

Pupils must realize quite early that diagrams must always be there for a definite purpose, and that they are not always necessary in the description of an experiment. For example, a pupil should not give identical sketches of both red and yellow phosphorus burning under a bell-jar, nor should he give the same sketch week after week of a test-tube being heated in a Bunsen flame. New apparatus should, however, be drawn in the note-books as soon as it has been used. In the preparation of the different gases, for example, it is advisable to show the new arrangement of the different parts of the apparatus. Sometimes a series of illustrations may be necessary or alternatively part of a drawing might be enlarged. Pupils ought to appreciate that scientific drawings are functional and *not primarily artistic*. The relationship between different parts of the apparatus should be clearly shown, and a pupil ought to be able to interpret the specific use of the apparatus without difficulty.

Sectional drawings.—Drawings in some kind of distinct outline are the easiest, both for young pupils and for those who find it difficult to make good sketches. The principle of the median longitudinal section gives the best results. With this system, the exact features of the apparatus can be shown, and the sketches can be executed in minimum time.

The free-hand diagram is the ideal for those with a moderate amount of skill. The use of compasses, coloured inks and shading should be discouraged. Stencils, which can be cut from celluloid or cardboard, are often helpful to weak pupils. Their chief disadvantage is that the relative size of each piece of apparatus is not easy to represent. Hence, if the teacher decides to allow their use, the pupils must be warned of this difficulty. Faintly-ruled squared paper is also most useful in the early stages to ensure correct positioning and proportions.

An alternative method for pupils who are weak in drawing is to allow the use of coins and narrow glass rods for drawing flasks and glass tubing. In practice, these mechanical aids are gradually dispensed with, but the habit of neatness frequently remains.

The sectional method of drawing can easily be described and its advantages pointed out by means of blackboard drawings. There is no necessity to give a plan, as most chemical apparatus is spherical or cylindrical. The front elevation is easy to draw and to understand. It is necessary, however, to make a rule that bends should be drawn at a convenient angle, and glass tubing be shown vertical or horizontal. The convention of showing ideal fittings should be adhered to even when the pupil bends his own glass tubing at awkward angles.

The diagrams of apparatus in this book illustrate the general principles of sectional drawings. All non-essential parts of the apparatus should be omitted, and the pupil should be shown the advantages of representing complex apparatus as if cut in half. Blackboard sketches should be used to show that under this system it is necessary to represent a tripod as having two straight legs joined by a horizontal line; a piece of wire gauze by a dotted or wavy line; a beaker by three straight lines joined by rounded corners (and without ellipses); a bosshead-clamp by rectangles or circles; and a clamp by two rectangles.

Apparatus which is difficult to represent on paper should be drawn on the blackboard. An average pupil cannot draw a distilling flask and condenser, for instance, with any degree of accuracy, unless the teacher illustrates the convention used for representing the arrangement of the inner and outer tubes, the clamps and retort

stand. Also, the first time large-scale apparatus is used, opportunity should be taken to draw a complete labelled diagram on the blackboard. Reference should be made to each part as the apparatus is assembled. Much repetition is required, and definite training is necessary for most pupils before the results are satisfactory.

It is necessary to adopt certain conventions for non-symmetrical apparatus. Whenever possible, these should be distinct and should be a near approach to the actual shape of the apparatus. Retort stands, burette taps and tube-furnaces must be represented by some simple method, and special instructions should be given when a complex piece of apparatus, such as the lead-chamber model for making sulphuric acid, has to be drawn. Thus, while the diagram essentially embodies the plan projection principle it is sometimes convenient to deviate from this method.

Pupils should make constant reference to their drawings when describing their experiments. In sketches of a simple type, the names of the different parts of the apparatus should be printed neatly at the side, but in a more complex diagram it is sometimes preferable to use letters for reference purposes. A key to these letters should be given in tabulated form. Emphasis should be laid on the necessity for labelling the less common components. Neat straight lines should be drawn from each label to terminate at the corresponding part of the apparatus.

Diagrams of industrial processes must occasionally be given. These should be drawn as quickly and simply as possible by concentrating on the essential parts, by avoiding decoration and shading, and by substituting simple shapes such as rectangles and circles for complicated figures. With experience, the majority of pupils find little difficulty in appreciating the full meaning of diagrams. For pupils who experience more trouble, drawings may be first roughly sketched on the blackboard showing the side and front elevations or the plan; models of industrial plants may be made in wood or card-board, or a method specially applicable to the manufacture may be devised. For example, in describing the Frasch process for the extraction of sulphur, most pupils are able to understand the sectional diagram. Those who experience difficulty may be helped to appreciate the three-dimensional aspect by reference to a set of cork-

borders or by drawing a series of concentric circles above the elevation to represent a horizontal cross-section.

The teacher should explain clearly the general principles of the sectional method to be adopted, and pupils should be told of the need for uniformity in representing certain components such as flasks, corks, tripods and glass tubing. This avoids much unnecessary correction of note-books. Pupils should not, however, be discouraged from devising their own conventional designs for Bunsen burners, clamps, bosses and wire gauze, if their designs are used consistently and conform to the general principles of the sectional method. Questions such as the following usually occur in the early stages of Chemistry-teaching, and the teacher must be quite clear in his own mind about the method he means to adopt. Must the supports—tongs, retort stand and clamps—always be given in the sketch? Is shading to be allowed? Are hidden parts to be shown by dotted lines? In what cases is the sectional method to be modified? Are simple signs, such as an arrow for a Bunsen burner, permissible? The writer prefers the inclusion of supports (though it is never necessary to draw hands, arms, etc.), and allows simple labelled signs for Bunsen burners, but excludes dotted lines for hidden glass tubing. Shading is allowed only where it serves a useful purpose.

As mentioned previously, pupils are not expected to reproduce sketches in the complete and expert style of those often found in text-books. Pupils' diagrams are for the definite purpose of indicating the particular use and position of part of the apparatus, or as a substitute for the written word. They serve as condensed descriptions of the apparatus, and can be used for reference purposes in future lessons or for revision.

Errors frequently made by pupils.—In discussing errors most commonly made by pupils, brief reference only will be made to the following points: different standards of skill in drawing diagrams are to be expected from pupils at various ages; pupils can be good chemists but poor draughtsmen; it is impossible for some pupils to attain any degree of neatness or skill in drawing apparatus. Stress will be laid on errors most frequently made by pupils whose drawings depart from the recommended convention of sectional

diagrams or are of no practical value. The following mistakes often occur, and some of them are indicated in Figure 38:—

Confusion in method. Partial sectional diagrams (c, k)—circles, ellipses, or straight lines drawn on mouths of beakers, test-tubes and ends of glass tubing—thickness of glass shown (i, j)—three legs on tripods.

Wrong proportions. Incorrect relative sizes of different parts of the apparatus; wrong relative amounts of reacting or resulting substances shown.

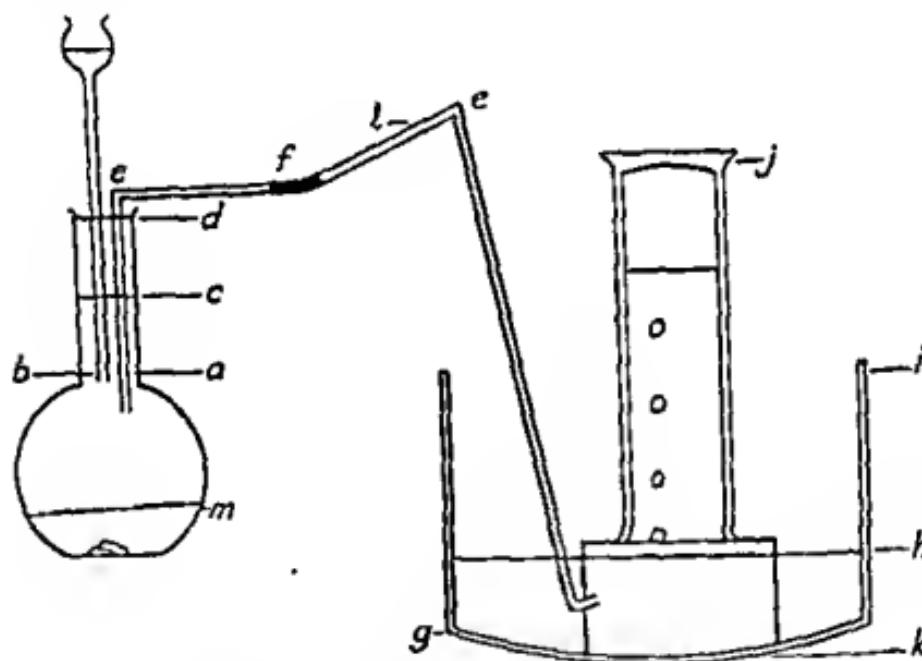


FIGURE 38.—Examples of mistakes in a sectional diagram

Too complex. Unnecessary detail—elaborate Bunsen burners; bases of gas-jars (j)—inclusion of gas-taps, water-taps, bench-tops and hands—shading and colouring—grain in wooden blocks, brick-work in industrial processes.

Incorrect position of different parts of apparatus. Not on bench (m and g)—unstable positions—wrong arrangement in fittings, e.g. wash-bottle—wrong angles of apparatus, e.g. Liebig's condenser—beaker not under funnel, Bunsen burner too far from flask—cork entirely in neck of flask (d)—liquid levels too high or too low in

Instances of the latter are charts showing the increased yearly production of synthetic nitrates and of aluminium. Instructive exercises are also provided by the collection of material from various sources, and by its arrangement for exhibition purposes. Encouragement can also be given to the correlation between Chemistry and other school subjects. The aid of boys who are weak in Chemistry and good at handwork can be enlisted in making apparatus of all kinds, in an attempt to increase their interest in the more theoretical topics.

The text-book should always be referred to when it contains a good diagram, but there are occasions when it will fail to supply the necessary help. A sketch, which the teacher considers essential for the work under discussion, may have been omitted from the text-book; a photograph illustrating an industrial process may be indistinct; an important part of a sketch may not be labelled, or a diagram of an obsolete process may be given. Sometimes a good diagram can be found in another text-book, but this is usually too small to show to a large class unless an episcope or a film-strip projector is available. Thus large wall-diagrams and charts are often necessary.

One object of this section is to suggest that the pupils themselves can produce useful wall-charts. These can consist either of modified drawings of the text-book diagrams, or can be specially designed to fit the syllabus. Sectional diagrams are advisable, and they should be as large as possible. These diagrams, drawn with Indian ink on white paper, or with white ink on black paper, are both cheap and effective. They may also be prepared by projecting the diagram on to a paper screen (e.g. using an episcope) or by tracing the outline in charcoal or chalk and then spraying with varnish. If necessary, the paper may be pasted on to three-ply wood and varnished. The sheets can then be easily stored by numbering each one and suspending them from a long wooden rod by string, and they can be kept from year to year. Sheets of cardboard or framed sheets of paper may be slid into a wooden frame at the side of the teacher's blackboard when required.

Diagrams and charts are of direct value for reference in class discussions. The following diagrams, for example, should always be available, in addition to the examples given elsewhere in this book: shapes of typical crystals; solubility curves; processes for liquefaction of air, extraction and purification of sulphur, 'fixation' of nitrogen,

manufacture of sodium carbonate, extraction of metals, and the manufacture of sulphuric acid. Coloured charts of the different indicators and their corresponding colours with different pH values, of flame-tests, borax beads, charcoal-block reduction-tests, mass spectra, and precipitates in the qualitative group tables, may also be of value when teaching older students.

Other diagrams supplement academic descriptions and provide information to pupils who need to enlarge their knowledge of certain subjects. Diagrams of value in this connexion are concerned with stills, refrigeration plants, historical apparatus, the hydrogenation of oils, the manufacture of soap, relative uses of fertilizers in agriculture, the water content of fruit and vegetables, the chemistry of the body, the composition of the earth's crust, the output of gas-works, the products from coal and coal-tar, the blast-furnace, the liquefaction of air, the structure of fire-extinguishers, and the composition of foods.

After several weeks' lessons on a series of substances which are prepared directly or indirectly from another key-substance, the problem of drawing up a chart to summarize all the reactions can be tackled by the class. A good student finds no difficulty in this, and it is an excellent exercise for slower students since, before they can complete their chart, they will have to re-read their notes and textbooks, and apply their knowledge intelligently. The best attempts serve as a basis for a large laboratory chart, and, when it is completed, the relationship of its contents to the whole of the course can be discussed. Charts of the type mentioned above can be drawn up around common salt and the alkali industry; potassium nitrate, nitric acid and its derivatives; sulphur (see Figure 39), carbon (see Figure 11), calcium, nitrogen and their compounds; the nitrogen cycle (see Figure 10); the carbon dioxide cycle (see Figure 11); different forms of the periodic table. Charts for the preparation of the common gases (see Figure 30), the valencies of the elements and radicals, the symbols used by the early chemists, and the percentage composition of the atmosphere may also be prepared. A chart on which are printed the important dates and events in the history of Chemistry should also be found in every school laboratory (see Figure 1).

If it is drawn up under parallel columns—Chemistry, other

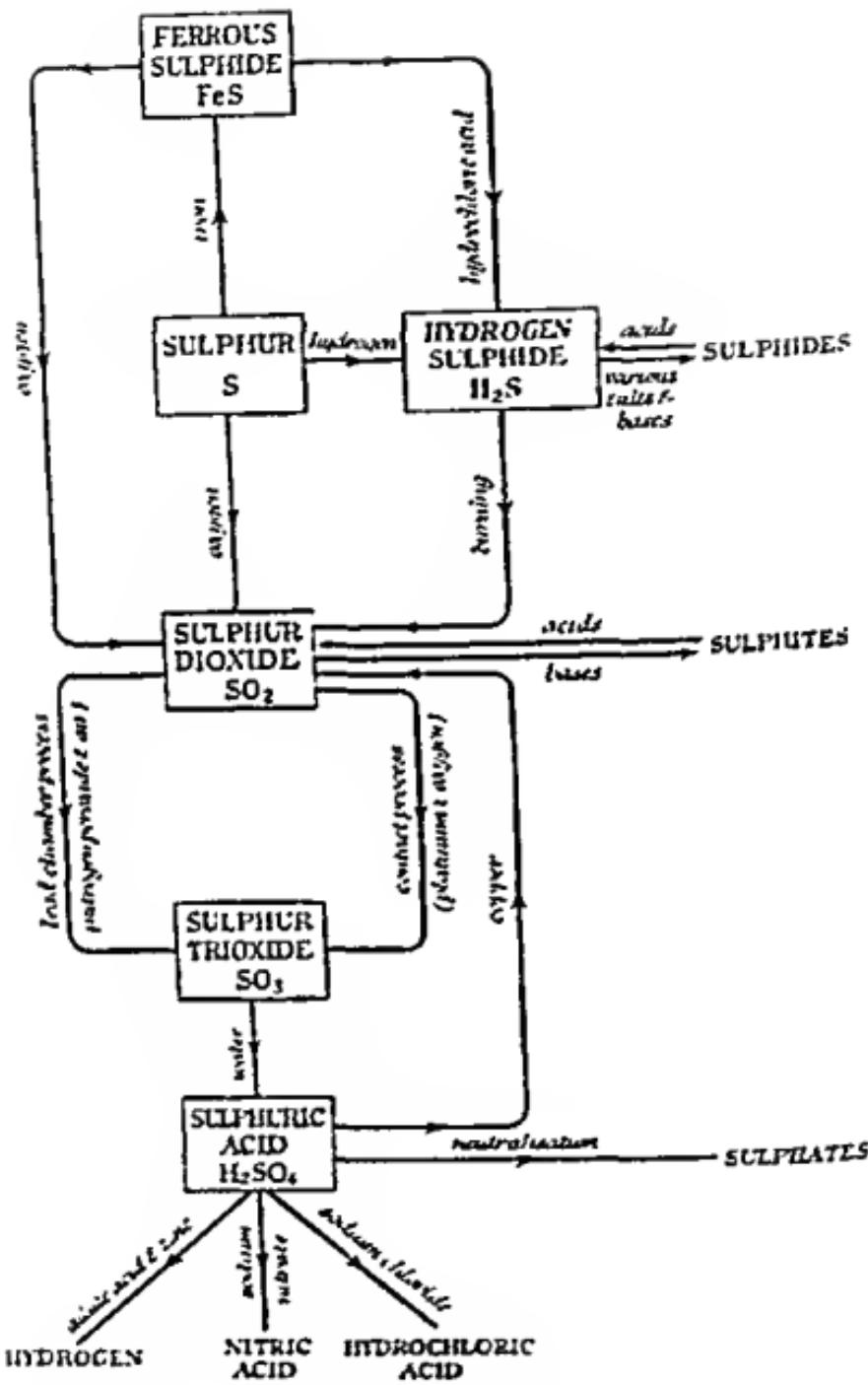


FIGURE 39.—Sulphur and its compounds: a chart

scientific discoveries, inventions, art, drama, music—the table may be used in other subjects as well as Chemistry.

Posters, advertisements, and cuttings from periodicals can often be used to form instructive charts. These should be arranged and pasted on a large sheet to illustrate a special point such as the importance of Chemistry in the home, local Chemistry, or some special occasion (e.g. the anniversary of the birth or death of some famous chemist). Pupils should be encouraged to bring illustrations from books and magazines whenever possible. Interesting photographs of things like stalactites and stalagmites, salt-pans, water softeners, lime-kilns and chemical works are often collected by the pupils if they are told that the subject is to be studied in the near future.

In Organic Chemistry, there is possibly still more opportunity for the use of systematic charts. Starch, sugar and wood can be the starting-points for the preparation of most of the aliphatic compounds (pp. 40-3). One compound can be shown to be derived from another, and this in turn can be converted into some other compound. The special properties of a radical or one member of a homologous series can also be tabulated. The drawing up of detailed summaries of the special properties of the aliphatic aldehyde, halide and hydroxyl radicals makes an excellent exercise. Examples of such charts are shown in Figures 2, 3 and 5. Similar charts for the aromatic compounds can originate from carbon, hydrogen, coal-tar, or benzene (see Figure 4). The general differences between organic and inorganic compounds, aliphatic and aromatic compounds, nucleus and side-chain compounds lend themselves to this treatment. Comparison and contrast, by this method, of the corresponding derivatives of the nucleus and side-chain compounds is also well worth attempting.

Models

The contact and lead-chamber processes for making sulphuric acid provide the best examples of manufacturing processes which can be carried out on a small scale. In the lead-chamber process the action of the catalyst nitrogen dioxide may be clearly shown by using stoppered jars containing sulphur dioxide and nitrogen dioxide and repeatedly exposing the resulting mixture of sulphur trioxide and nitric oxide to the oxygen of the air. Laboratory methods to illustrate the

commercial preparation of potassium chlorate, sodium bicarbonate, potassium bromide, white lead and chlorine may also be carried out effectively. Although poor yields may be obtained by these laboratory methods, the principles governing the manufacturing processes are made clear.

A dull theoretical lesson can be enlivened by a stationary or scenic model constructed in coloured cardboard or wood.

If this is made in the school workshop, it has an added appeal. Complicated sketches are unsatisfactory for pupils who can neither



FIGURE 40.—The manufacture of sodium: a model of the Castner process

visualize the actual apparatus nor completely understand its three-dimensional aspect; it is to these pupils that models are particularly helpful. The time given to making a small still, or a model of a coal-gas works, a modern blast furnace, or the lead-chamber process, in cardboard or wood, is time well spent.

Another type of model may be constructed to show the individual portions of a complicated industrial plant. One example is the Castner process for the manufacture of sodium. Before the model is shown, the principle of the process might be demonstrated by the electrolysis of molten sodium hydroxide. The wooden model is built as a 14-inch side solid cube which is hinged into two halves (Figure 40). (It is better to screw the hinges into the sides rather

than to the base.) The closed cube shows the outside fittings of the electrodes, gas-pipes and outlets. The pupils can readily see that the iron vessel and electrodes are cylindrical. When the box is opened the inner parts of the plant are represented by a drawing (see Figure 41). This model helps the weaker pupils to visualize and understand the actual plant.

Another type may be a 'working' model or a modified model

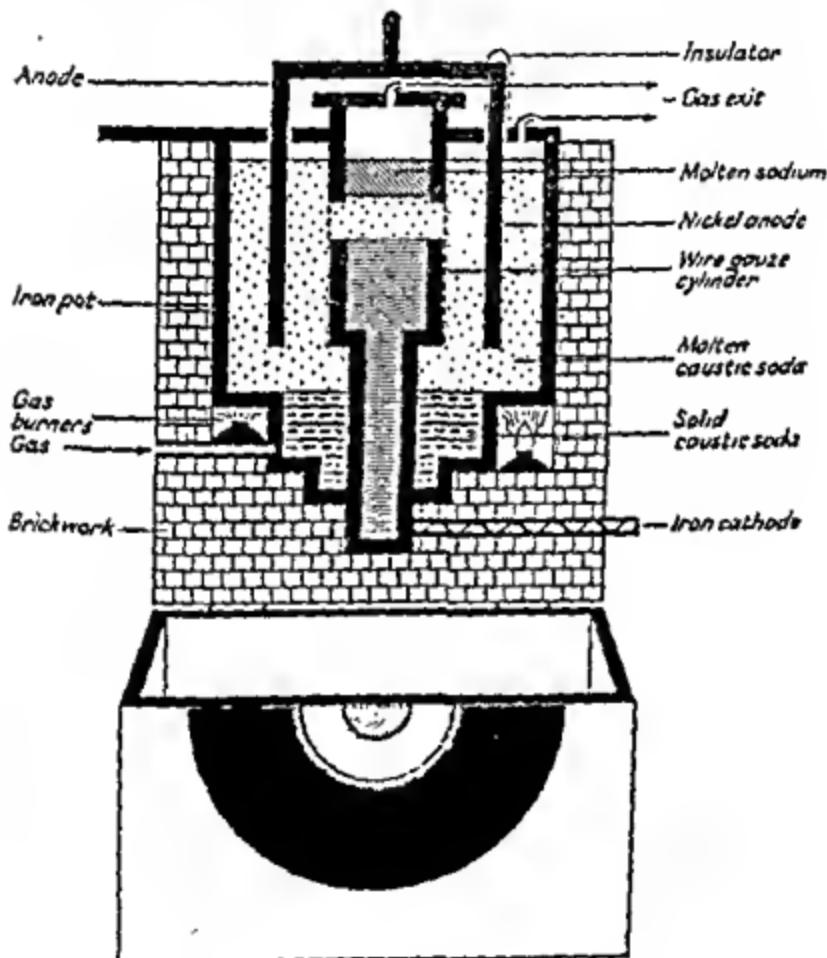


FIGURE 41.—The Caster process: interior of the model

adapted to a special use. Interesting examples of these are required for studying the alkali industry. After electrolysing sodium chloride solution by placing the two electrodes in a beaker and then in a U-tube, the Castner-Kellner process for the manufacture of sodium hydroxide can be illustrated. A wooden box with three compartments is used to suggest the construction of the plant. Glass is placed in front of the box so that the inside can be seen, and dry sand is rocked backwards and forwards to show the use of the mercury and the eccentric. This movement is caused by turning a disc at one end of the box and by allowing the other end to rest on a wedge. Important parts of the plant such as the anode, cathode, the chemicals, and the outlet pipes for the hydrogen and oxygen are distinctly labelled. A convenient method of doing this is to fasten labels to a piece of wire and to attach these to the parts to be described.

With junior pupils, other ideas can be developed. A model of a blast-furnace can be made in wood, painted and appropriately labelled. White sand or other suitable material can be dyed and used to represent the raw iron ore, coke and limestone which are run into the top of the furnace. Other coloured material can be placed inside the model in stoppered tubing so that 'iron' or 'slag' can be removed from the bottom of the furnace. Coloured lights make the process more realistic. If necessary, the development of the iron industry, throughout the ages, may be shown by a series of model furnaces. This might serve as a topic for a school exhibition.

These examples are typical of many that can be devised for use in schools either as part of the normal curriculum or as part of a project. Permanent models of a particular local industry which lends itself to such treatment may be preserved and used for years, and it is in schools where the teachers of handwork, woodwork, metalwork and Science co-operate that pupils derive the maximum benefit from such joint activities.

Other forms of teaching aids

The teaching aids, often known as 'visual' or 'audio-visual', include the episcope, micro-projector, film-strip projector, and silent or sound film projector. Each has its own advantages and limitations in the teaching of Chemistry, and should be used only when it can

provide something the teacher cannot provide by other means. It may be said in favour of the use of such aids that:—

(a) Some children learn more readily from this kind of visual presentation.

(b) Background knowledge, and complementary material and illustrations, can more easily be supplied: e.g. historical information, the working of industrial processes, etc.

(c) Pupils see and hear accounts and explanations from experts.

The teacher's attention is drawn to the following points:—

(i) The quality of reproduction, for both sight and sound, must be high, otherwise the lessons will have little value. Children with experience of the commercial cinema should not be able to make unfavourable comparisons.

(ii) As a general rule educational films should be shown to one class at a time.

(iii) The teacher must see a film in advance, and decide on his line of approach for a suitable introduction to the class. After the first showing he will often have to instruct pupils to pay attention to particular points, and will then show the film again. Immediate follow-up work will be necessary, and further references to the subject may be required at a later date.

(iv) The building up of a film-strip or film library is usually impossible in any one school. It should be done, wherever possible, on an area basis, with a number of schools combining. Each school should have a catalogue of the available material.

(v) Aids of the kind under consideration may be assembled with diagrams, charts, models, etc., to form a complete visual aid unit for some topic or project—e.g. a coal-mine.

(vi) *Screens.* The roll-up type is easy to move, but the results are not so good as those with a fixed screen. The best surface for a fixed screen is titanium-white on a smooth white plaster wall, or on a movable glass screen, and is preferable to a silvered surface. If projection from the rear is more convenient, then a translucent screen should be obtained.

Advantages and disadvantages of the apparatus are as follows:—

Film-strips.—Advantages: (a) The projector is cheap, easy to use and to carry about.

(b) The strips are cheap, easy to store, and are produced in great variety.

(c) Individual pictures remain in the same order, but the strip may be stopped at any stage and turned backwards or forwards.

(d) The teacher can give what he regards as the most suitable commentary. (Notes are usually supplied with the strip.)

(e) A semi-darkened room permits satisfactory vision, and at the same time allows pupils to write notes.

Disadvantages: (i) The rigid sequence of the pictures may not suit the teacher's ideas for the treatment of the topic.

(ii) The presentation depends on the skill of the teacher: there is no movement or dramatization.

(iii) The sprocket holes become worn, and the surface of the film is easily scratched. For this reason many teachers prefer to use slides.

Sound films.—The 16 mm. projector is usual for school use. Some of the films can also be shown silently.

Advantages: (a) Many children nowadays accept them as a usual means of instruction and recreation.

(b) The time-sequence and the three-dimensional aspect become more obvious in a moving picture, e.g. component parts of an apparatus in motion.

(c) Experts, who can be seen in person, give first-class expositions on their subjects. Dramatization of historical occasions is sometimes possible.

Disadvantages: (i) Costs of projector and films are high.

(ii) The commentary is fixed, and many teachers prefer to give their own because they know the needs and interests of the class.

(iii) Turning back, to stress some particular point, is neither easy nor satisfactory.

(iv) School rooms seldom give good acoustic results.

(v) It is often difficult to darken a room sufficiently.

Silent films.—Some of the above comments are applicable.

Advantages: (a) The projector is cheaper than that for sound films.

(b) It is easy to stop the film and study a particular picture as required.

(c) The teacher is able to supply the commentary he desires.

Micro-projector.—This is comparatively cheap and may be regarded as less of a luxury than film-projectors. In many schools it is in frequent use for the teaching of Biology, and can be made available for Chemistry lessons as required. Additional advantages are: (a) The room need not be only semi-darkened.

(b) Only one microscope is necessary, and all pupils can see clearly the 'picture' on the screen.

(c) Small objects, such as crystals, are readily mounted on a slide.

(d) The teacher is able to point out distinctive features to all pupils at the same time.

(e) Projection on to a paper screen enables the teacher to make a permanent drawing accurately and quickly.

CHAPTER XII

Training in Experimental Technique

Until recent years, the development of practical Chemistry in schools was handicapped by several influences. Laboratories were supplied with insufficient and often unsuitable apparatus; large classes were taught by one teacher; and small rooms were adapted as laboratories, with little regard for the number of pupils to be taught there. In some schools, Chemistry is still taught in classrooms, and even large schools are often without full-time laboratory assistants.

During more recent years, laboratories have been included as an essential part of new school buildings, and the general conditions have improved. It will be a long time, however, before all have reasonably spacious laboratories with proper fittings and adequate equipment. In fact, the material conditions prevailing in different schools are so varied that Chemistry courses, of necessity, differ considerably in both content and method.

Use of simple apparatus

A plea is made here for the use of simple apparatus. It is believed that the use of ready-made apparatus, particularly of a complex type, is often likely to handicap the progress of a junior pupil. Simplified apparatus may not give ideal results, but it improves the skill of the operator and is, in most cases, more appropriate for elementary pupils. It should be realized that an important aim in carrying out experiments is to improve the technique of the experimenter, and that the methods employed are of as great importance as the mechanical attainment of a good result. Great care, therefore, must be taken in selecting suitable experiments and in framing simple and clear instructions. Pupils must be given opportunities for carrying out individual experiments with simple types of apparatus or with improvised forms of the standard type. Wohler's description of Berzelius' laboratory shows that a great chemist could work with very simple and limited apparatus:—

"No water, no gas, no hoods, no oven were to be seen; a couple of

plain tables, a blowpipe, a few shelves with bottles, a little simple apparatus, and a large water bottle, whereat Anna, the ancient cook of the establishment, washed the laboratory dishes, completed the furnishings of the room famous throughout Europe for the work which had been done in it. In the kitchen, which adjoined, where Anna cooked, was a small furnace for heating purposes.'

Complex apparatus on a large scale may be used in a demonstration, when the numerous parts are explained in detail, but in an individual experiment, such fittings are unnecessary as they distract attention from the main issue. Further, there is a definite educational value if the pupil is allowed to suggest the method of procedure and the kind of apparatus to be used. The latter will usually be of a simple type. Better work is often done when test-tubes and standard glass fittings are used in preference to larger apparatus (see Chapter VIII): pupils have more opportunities of working individually, and the use of small amounts of material enables the experiment to be completed in shorter time. Moreover, these methods are more economical, and are much more convenient for the preparation of objectionable gases when sufficient fume-cupboards are not available.

Occasionally the method of carrying out an experiment might be left to the ingenuity of the pupils. The experiment then becomes a personal one. The pupil is eager to try out his ideas, and so anxious is he for it to be a success that he takes much more care than would be the case with more conventional apparatus. It is an advantage also for the pupil to see the ideas of classmates being carried out in attempts to solve the same problem.

The comparative use of apparatus

Although practical work in Chemistry may be termed 'organized common sense', it has a technique which is too often neglected. A natural proficiency in laboratory work is rare. Laboratory technique must gradually be built up by the best use of both demonstrations and individual experiments. Occasionally, it may be necessary to resort to 'drill' methods, for example, with large classes when a test-tube is being heated or when the stopper of a reagent bottle is being removed for the first time. These methods are, however, not to be generally recommended.

Good habits should be inculcated from the earliest years. Leading

questions put to individual pupils during the progress of the first few practical lessons are invaluable. By holding his hand a few inches above the Bunsen burner, a pupil will realize that it is warm enough there to keep water boiling gently. Simple experiments with a piece of glass tubing and with paper illustrate which part of the flame is hottest. The pupil should be told the temperature and position of the hottest part of the cone, and he will then realize that glass placed suddenly in the flame will break. The pupil should also know when to use 'hard' or 'soft' glass test-tubes and apparatus of thick or thin glass, and be able to give reasons for his choice. He should use a flexible metal tube, with a sheet of asbestos on the bench, if long heating is necessary.

Correlation of practical work

Revision questions for homework, or individual questions in class, should help the pupil to realize the relative suitability of different pieces of apparatus. He should, for example, know whether a Woulfe's bottle, round-bottomed flask, flat-bottomed flask or retort is advisable for the preparation of hydrogen, nitric oxide or chlorine. He should know when it is advisable to have a safety-bottle connected to his apparatus so that water does not run back. He should be able to explain intelligently when a gas should be dried and how to carry out the process. His ingenuity is tested by finding out if the apparatus used in the gasholder preparation of nitrogen, or the siphon experiment in the determination of equivalent weights, is air-tight.

Further, he should note the physical differences between materials employed in preparations. It is an advantage to have a large area of metal when passing steam over heated iron filings and air over heated copper turnings. On the other hand, a small area is an advantage in the preparation of hydrochloric acid from rock salt and concentrated sulphuric acid, or of carbon dioxide from lumps of marble and dilute hydrochloric acid. Many interesting points are raised in discussing the different ways of increasing the rate of filtration when washing precipitates. These and similar questions offer great scope to intelligent and practical pupils.

Incidental teaching

Accidents, especially with sodium and phosphorus, must be pre-

vented, and the comparative actions of the two on water and mineral oil should be emphasized. The occasional explosion of a small piece of weighted sodium in water demonstrates forcibly that the full reasons for the occurrence of this phenomenon are, at present, beyond the knowledge of the chemist.

It is advisable, also, to stress any incidental point which may arise through a mistake or an accident.

At an early opportunity the teacher should warn the young pupil of the danger of looking directly into the mouth of a test-tube and of putting his thumb on its mouth and shaking up its contents. The pupil should be trained to add very small amounts of material to a liquid, to shake the test-tube gently or to stir it with a glass rod. When using reagents he should be shown the great sensitivity of many tests. He might, for example, put 1 c.c. of copper sulphate solution into a test-tube, pour it into the sink and test with ammonium hydroxide for the residue left behind on the walls of the test-tube. One gram of copper sulphate ($\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$) might be dissolved in water and made up to one litre so that 1 c.c. contains 0.001 g. This might be diluted further to find the limit of sensitivity of the test with ammonium hydroxide. Similar tests might be done with solutions of ferric chloride and potassium thiocyanate, lead acetate and potassium chromate.

If a young experimenter sees his carefully prepared distilled water, copper sulphate solution or concentrated nitric acid thrown down the sink after he has completed the necessary tests, he feels discouraged. This is especially so when he has previously been told, for example, that the nitric acid is pure because it has been distilled. It is worth while collecting these samples for further use, even if it is thought inexpedient to pour them into the reagent bottles. Mercury, silver, and iodine residues should also be collected, put into bottles, and kept for recovery. If potassium nitrate has been prepared as a class experiment, its use in the making of gunpowder can be demonstrated. Alternatively, pupils can show its efficiency as a fuse by using a solution and a piece of string.

Practical problems

Pupils who have passed the junior stage will derive great benefit from solving genuine research problems. For example, sound research

work has been done by boys on the burning of magnesium. They found that the carbonate, nitride and silicide of magnesium are formed in addition to the oxide. Pupils of the writer have done original work on colouring matters in plants and their use as indicators; and also on fruit essences, paints, micro-chemistry, and various aspects of local Chemistry.

All teachers would not go to the extent of asking their students to solve problems to which they themselves do not know the answer. Much good work may be done in the laboratory, however, on the analysis of air, water and samples of local minerals; the estimation of the amount of free iron present in ferrous sulphide; the percentages of free alkali and sodium stearate in cheap soap; the amount of citric or tartaric acid in 'lemonade powders'; and the percentage of acid in vinegar and sour milk. Alternatively, suitable unsolved problems might be suggested by research workers. The examination of large reference books or text-books reveals many unsolved problems. The solubility of certain substances has not been determined, and the existence of double salts might be investigated. One method suggested is that one school should work on the properties of one salt. For example, the conductivity, molecular weights in various solvents, double salts, double compounds with alcohol, and the composition and crystalline form of hydrates might afford useful preparations and analytical tests. Each pupil would feel that he was doing new work, while the individual efforts could be recorded and classified over a number of years and, if the topics selected were not one of the commonest, genuine new knowledge would be gained.

It is not unusual for a boy's parents to ask a Chemistry teacher for help. The following are examples of problems teachers have been asked to solve: to harden animal gut for a tennis racket; to determine the percentage of ammonia in cow's blood; to find if the water in a cellar had come from a leaking household pipe or from outside the house; to discover a cheap solvent for lemon oil; to analyse a weed-killer; to find the percentage of water and carbon dioxide given off from different samples of washing or baking soda; identification of metals in tubes and containers of different types. These and similar problems can occasionally be worked out by the senior boys. In fact, every opportunity should be taken to give the student problems which can be solved by using the facts he already knows. Juniors should also

receive training in solving practical problems. This can be accomplished by framing laboratory instructions as a problem. Advanced students, however, when nearing the end of their course, might be set definite research work.

The Report of the British Association on 'Science Teaching in Secondary Schools' supports this method. It says: 'The problem method aims at suggesting a motive and purpose for every experiment and thus of creating the spirit of experimental inquiry. It consists in facing a problem and by means of experiments endeavouring to solve it and related problems which arise during the work. The intention is not, as is sometimes supposed, to make pupils discover for themselves things such as laws and principles which are unknown to them, though to some extent this can be done. The experiment to be undertaken by the pupil may arise from his own demand, or be assigned by his teacher to clear up some observed misapprehension, or as a challenge to test his knowledge of what he has been taught, and his resourcefulness, or simply to give the final security of his personal practical experience.'

Generalizations

As the pupil gains more experience in the laboratory, mere repetition experiments should be avoided. He should be trained to anticipate new results by analogy and comparison, without necessarily following out the practical observations and experiments. Thus, when he has found out that carbon dioxide is evolved from magnesium carbonate with dilute nitric acid, and that, under the same conditions, chalk gives the same gas, he should appreciate that, in general, all carbonates evolve carbon dioxide with all acids. Alternatively, the point may effectively be introduced in problem form by examining the action of dilute acids on various carbonates. After the pupil has prepared copper sulphate from copper oxide and dilute sulphuric acid, lead nitrate from lead carbonate and dilute nitric acid, magnesium sulphate from magnesium carbonate and dilute sulphuric acid, and sodium chloride from sodium hydroxide and hydrochloric acid, oral exercises should be given to bring out the general methods of preparing salts. It should be mentioned that these generalizations only apply when solution occurs (e.g. lead will not dissolve in dilute acids), and also that salts of metals (and not of non-metals) are

formed. This will help to prevent the mistake so often made when pupils state that salts of non-metals, such as carbon or sulphur, can be prepared.

A class-problem in the first year

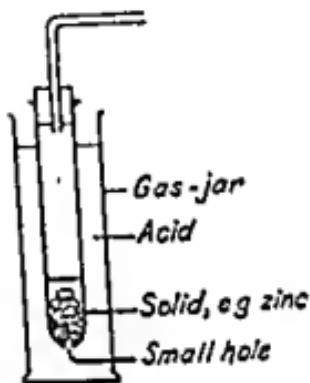
When sodium is dropped on to water, the pupils see that it dashes about, dissolves and only gives a yellow-coloured light when it hits the side of the vessel. What is the source of the light? The suggestion that because the sodium is kept comparatively still for a short time it cannot dissipate the heat evolved, and therefore the hydrogen given off ignites, seems to be a sensible one. How can this be shown? Unsuitable suggestions for putting an empty test-tube over the sodium, dropping sodium into a test-tube, or gripping it with a pair of tongs are probably given. Some pupils may suggest that the surface of the water should be made viscous with starch, chalk powder, or sawdust, or that the sodium be placed on a floating piece of filter-paper. The various ideas put forward should then be discussed and, if possible, tried out. Next, the question of the yellow hydrogen flame should be discussed, and a method for collecting the evolved hydrogen sought. Usually, a test-tube with a delivery tube is first mentioned, and this, along with the idea of putting sodium on the surface of the water and covering it with a gas-jar full of water, are eventually considered to be impracticable and too dangerous. Next, it is suggested that the sodium should be sunk. How? The method of tying on a weight with a piece of cotton is criticized adversely by the more intelligent members of the class. Finally, ideas of putting a small piece of the metal into a copper or lead tube, a wire-gauze cage, or an aluminium-foil jacket are suggested and tried.

Such problems call for the heuristic method. They require scientific thought and the application of previously known facts. They develop the initiative of the pupil, and at the same time are much more interesting than an experiment carried out mechanically from written instructions of a didactic nature.

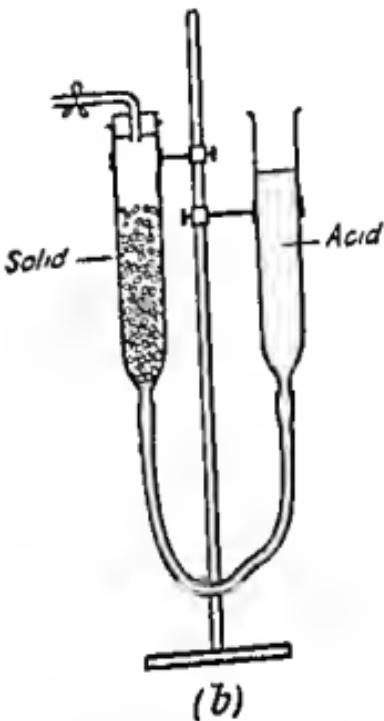
Devising apparatus to solve practical problems

Problems should be given to encourage the development of experimental technique. It is desirable for the pupils to have opportunities for suggesting the kind of apparatus they would like to use, and to

allow them gradually to assemble, even in imagination, improvised apparatus. Let them describe it, even if the pattern is unusual, for the animated class discussion of its weaknesses is most enlightening.



(a)



(b)

FIGURE 42.—The laboratory supply of hydrogen sulphide, carbon dioxide, hydrogen, etc.: substitutes for a Kipp's apparatus

- (a) When the gas supply is no longer required, the test-tube is removed from the jar. (It may be washed through with water to stop the reaction immediately.)
- (b) The acid reservoir is lowered to stop the gas supply.

Problems of the following type can be set for homework.
Design apparatus:—

- (a) As a substitute for a Kipp's apparatus to give a continuous supply of carbon dioxide (see Figure 42).
- (b) To electrolyze water so that the evolved oxygen and hydrogen may be collected. Preferably use an old 'high tension' battery (perhaps from a disused battery radio-set) and scrap materials.

- (c) To show that when concentrated hydrochloric acid is electrolyzed, it gives off equal volumes of hydrogen and chlorine.
- (d) To demonstrate to a large class of pupils that concentrated sodium chloride solution is decomposed by an electric current, and that it forms sodium hydroxide and chlorine.
- (e) Using a school balance, or an improvised one, to show by a mechanical device when an object gains, loses, or does not change in weight.
- (f) To show that manganese dioxide acts as a catalyst in the 'oxygen mixture' (see Figure 43).

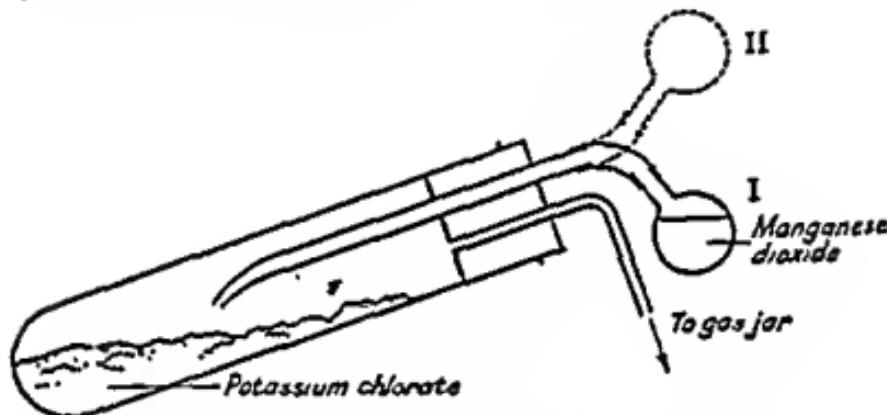


FIGURE 43.—The small-scale preparation of oxygen: to show that manganese dioxide is a catalyst

- (g) To show that aluminium foil, after being rubbed with mercury, removes oxygen from air.
- (h) To determine the percentage of dissolved air in tap-water.
- (i) To show the presence of the elements in copper sulphate or lead nitrate.
- (j) To verify the law of conservation of mass, using, firstly, any two liquids, and, secondly, a match (see Figures 44 and 45).

Problems connected with experimental results quoted in newspapers and journals are stimulating. Other problems will occur to the teacher which will bring variety to the usual work and be of value in training the pupil in the use of the scientific method.

Laboratory instruction

Attention must be paid to the way in which instructions are worded.

Early in the course, they must be in simple straightforward language which the pupil thoroughly understands. Later, however, the time-saving technical phrases should not be avoided. The pupil must always have his observations and readings directed in the proper way. He should be clear on the amounts of substances to be used, preferably in known units and in small quantities. He should be guided to concentrate on the main object of the experiment and to avoid side issues. Thus, in noting the changes which take place when sulphur is heated, the instructions to him should point out that colour and consistency are the chief points to be noted, and that no special attention need be paid to the smell of the evolved sulphur dioxide. In a test-tube preparation of hydrogen chloride, the pupil should be told of the necessity for using small amounts to avoid troublesome effervescence, and besides noting the physical properties and the acidity of the gas, he should be instructed to blow across the mouth of the test-tube and to test the gas with drops of silver nitrate and ammonium hydroxide solution suspended on glass rods.

If it is desired to prevent the occurrence of interesting but distracting phenomena, such as an unusual precipitation, or the burning of the molten sulphur from which prismatic sulphur is being made, or the uncontrollable activity of aluminium dust when heated with dilute acid, definite instructions on how to avoid them must be given.

It should be recognized that whenever possible the instructions should be given in problem form or as a series of questions. Thus, for example, in the *formation of metallic sulphides*.—In a 4-inch test-tube held in crucible tongs heat 2 c.c. of powdered roll sulphur until it begins to boil. Carefully drop a thin strip of copper foil into the vapour and remove the Bunsen flame when a change begins. Report on the appearance and properties of the resulting substances. Was the temperature of the reaction higher at any time than the Bunsen flame alone could produce? If so, was the increase in temperature due to the sulphur vapour, copper, Bunsen flame or some other source? Name and describe the new product and give the equation for its formation. Cool, then pour dilute hydrochloric acid on to a little of the solid (compare with ferrous sulphide), and try the action of other dilute acids on the product.

Another problem, to serve as an introduction to oxidizing agents after chlorine has been studied, might be worded as follows:—In the

action of concentrated hydrochloric acid on compounds.—Pour 2 c.c. of concentrated hydrochloric acid into a test-tube. Add a very small amount of copper oxide. Does the substance dissolve easily? Is it necessary to warm in order to start the reaction? Is a gas evolved? Test with litmus paper and perform other tests. What solid is formed? Repeat the experiment, using in turn manganese dioxide, litharge, lead peroxide, potassium chlorate, and magnesium oxide. What conclusion do you draw from all your results? With which substances does concentrated hydrochloric acid evolve chlorine? Verify with other substances in the laboratory such as calcium oxide and potassium bichromate.

In this way the preparation of chlorine, oxidizing agents, formation of a salt, equations, identification of substances and the testing of hypotheses may all be revised or introduced. In addition, the problem is not only treated in a scientific manner, but it avoids monotony and therefore holds the interest of the pupils.

Some problems.—The following are problems which may be given to pupils of almost any age who have some knowledge of Chemistry.

(a) *To show that manganese dioxide acts as a catalyst in the preparation of oxygen.*—It is most interesting to observe how pupils attempt to introduce the catalyst, standardize the conditions, and adapt to the problem the apparatus with which they are acquainted. There are many failures, and much unwieldy and unsuitable apparatus is suggested. This is, however, quickly criticized by intelligent members of the class. The members of one class suggested the following methods, which are given briefly without the accompanying sketches.

1. Place 4 g. of potassium chlorate in a flask connected to a delivery tube and a pneumatic trough. Heat until no more oxygen is evolved and take the time which has elapsed. Compare the times on repeating the experiment with 4 g. of potassium chlorate and 1 g. of manganese dioxide.

2. Heat potassium chlorate in a test-tube until it melts. Add a little manganese dioxide and test (with a glowing splint), before and after the addition, to compare the amount of oxygen given off.

3. Connect a thistle funnel and a delivery tube to a flask containing

potassium chlorate. Heat and take the time (from the appearance of the first bubble to the last) to fill one gas-jar using a stop-watch or counting seconds. Quickly introduce the manganese dioxide, and again note the time to fill one gas-jar.

4. Heat one flask containing potassium chlorate and another containing the same weight of potassium chlorate plus the catalyst with the same Bunsen flame under the same conditions. Measure the volume of oxygen liberated from each or compare the weights of both flasks. Note which gives off oxygen the quicker or which loses the more weight.

5. Heat the same weight of potassium chlorate in a cylindrical chamber divided into two parts. Place one-fifth of the amount of the catalyst in one. Collect the same volume of oxygen given off from the two compartments and compare the times.

6. Blow a bulb on the end of a 3-inch piece of glass tubing. Fill with the catalyst and join by rubber tubing to another piece of glass tubing, which passes through the cork of the apparatus used to prepare oxygen. Bend the tubing at the end and let it be sufficiently long to pass into the middle of the test-tube (see Figure 43). Heat the potassium chlorate until bubbles of oxygen steadily rise in a gas-jar. Remove the flame, lift the bulb into position II, so that the catalyst runs on to the molten potassium chlorate, and note the increased evolution of oxygen.

(b) *Problem on the oxidation of aluminium foil.*—Aluminium foil in air forms a protective coating, probably of aluminium oxide; when the foil is rubbed with mercury (or cleaned with sodium hydroxide solution and dipped into mercuric chloride solution), it forms aluminium amalgam and the protective oxide film is removed. The aluminium then oxidizes very quickly, forming long white growths of aluminium oxide or hydroxide.

The above facts can be mentioned, and pupils can be asked to state how they could use them to show that air or oxygen is the cause of the formation of the white growths.

The following ideas were obtained from a form of first-year pupils:

1. Put part of the cleaned metal in sand and leave the other part exposed to the air. Note the difference.

2. Compare the action on part of the metal coated with vaseline with the other part.

3. Put half of the foil into a jar of air, and the other half into a jar in which the oxygen has been removed. Compare the two results.

4. Put a hook on a ground-glass plate and fasten a rectangle of the foil on it and put into a jar of oxygen. Repeat with a jar of nitrogen.

5. Put half of the foil into water which has been boiled to remove the dissolved air, and note the difference from the half left in the air.

6. Place a piece of aluminium foil in an evacuated distilling flask which is joined to a hard-glass test-tube containing mercuric oxide. Heat the mercuric oxide and see if the mercury forms an amalgam, and if the oxygen causes white growths to form.

(c) *To show that there is no loss or gain in weight in a chemical change.*—The first suggestion put forward by members of the class was an indefinite one, namely, to weigh the reactants. This was amplified by the statement that beakers containing sodium chloride and silver nitrate solutions should be weighed, one solution poured into another and the whole re-weighed. One pupil suggested that the same experiment might be performed by placing one solution in a beaker, the other in a flask fitted with a cork and thistle funnel, and allowing the two to react in the flask. This evoked the criticism that if a gas was evolved it would escape unless the stem of the thistle funnel was lowered into the solution to act as a safety-valve.

As soon as the idea of a closed space was mentioned, the problem was set for homework, and it was found that many pieces of apparatus, quite as effective as the standard ones, were suggested by intelligent pupils. Some of these, along with interesting errors, are shown in Figures 44 and 45. Whenever possible pupils should be allowed to use the apparatus they suggest.

Unusual proposals must not be ignored. Thus the balancing of two magnesium flash-light bulbs (used in photography) on a long piece of wood pivoted on a nail, and igniting one of the bulbs, leads to useful discussion on teaching-points concerned with the laws of conservation of mass and of energy.

Chemistry as a hobby

Finally, the use of improvised apparatus should be encouraged, as there are always a number of pupils who may choose Chemistry as their hobby. Many pupils try out experiments to make crystals, invisible inks, fuses and fire extinguishers, or perform interesting

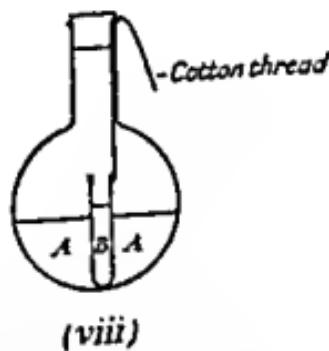
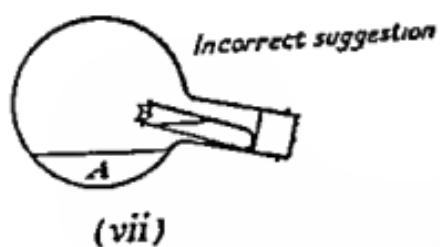
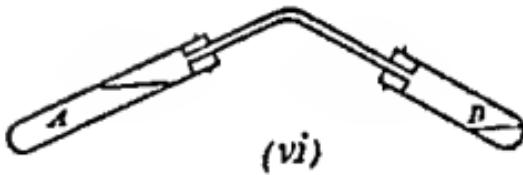
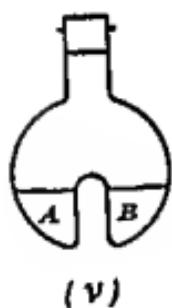
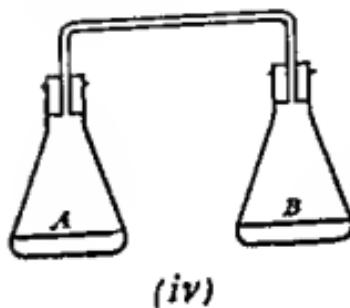
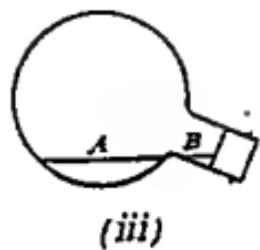
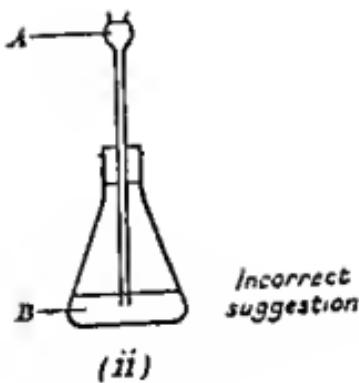
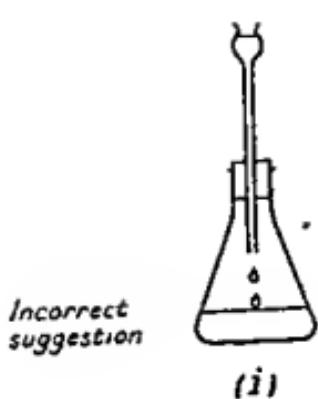


FIGURE 44.—The law of conservation of mass: pupils' suggestions for experimental proof (using two liquids)

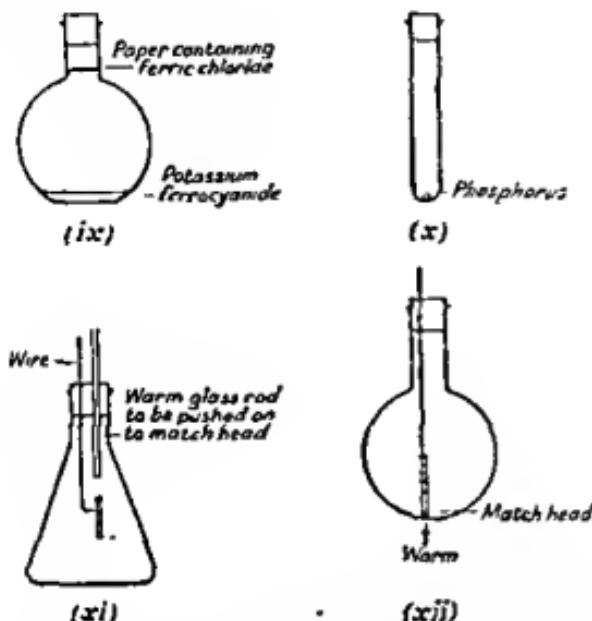


FIGURE 45.—The law of conservation of mass: further experimental suggestions

experiments such as filling soap bubbles with coal-gas or carbon dioxide. Others are attracted by the applications of Chemistry to everyday life, and are more concerned with making baking-powder, 'health salts', fertilizers, 'lemonade powders', and even face-powders and creams. One author states that two powdered potassium chlorate tablets and a little manganese dioxide on heating yield six gas-jars of oxygen. A few matchsticks heated on a tin lid provide sufficient wood-charcoal to absorb the nitrogen dioxide filling a test-tube. Vacuum-flasks are useful containers to show the evolution of heat when acids and alkalis are mixed and for more advanced experiments in thermo-chemistry.

Pupils with such interests become familiar with chemical phrases and often take a delight in using them. They repeat class experiments at home, improve their laboratory technique, and are often to be found at the top of their class. They set a good example to the rest by their keenness and resource, and in consequence they should be encouraged by being given, whenever possible, references to suitable experiments and helpful library books.

CHAPTER XIII

Basing the Science Course on Environment: School Projects

Chemistry and the General Science syllabus

The necessity for the school curriculum to be connected with the environment is stressed in many official publications. The report of the English Ministry of Education on 'Science in Senior Schools' states: 'It is to be expected that there should be a great variety in the schemes and syllabuses, corresponding not only to the variety of the children's capacities, but also to the great diversity in local environment. It is not encouraging to find that few of the schools visited had attempted to plan their courses on the basis of phenomena already familiar to the children in their ordinary lives or easily accessible in local industries and occupations.'

It is not necessary to base the whole of the school Science course on the environment—often it is impossible—but even with academic courses an occasional starting-point may have a local bias. Much realistic work related to the life of rural or industrial communities can be done in secondary schools of all kinds. The geographical and historical reasons for the development of a special industry, the climatic and geological conditions affecting local agriculture, or the uses of local supplies of ore, limestone, clay or coal, may all be used as starting-points for fruitful discussion and research.

The pupils should be given reasons for the occurrence and importance of local industries, and be made to realize the part these activities play in the communal life. A survey of the area around the school might be attempted. This should include parents' occupations, industries, density of population, town-planning and scope for future development. If the teacher, for example, is interested in local history or welfare work, these aspects should be developed because the enthusiasm with which they are taught will do much to help the pupil to take an active part in future work of a similar character. In some cases, there may appear to be little connexion with Science, but these school regional surveys extend beyond the scope of an individual subject.

The actual experience of children is often severely restricted, as many travel but a limited distance from their own homes. If, however, they can be given an interest in the chemicals and machinery that are conveyed from all parts of the world to the local farms or factories, their outlook will be widened, and they will learn to investigate with more enthusiasm the larger world around them. Moreover, when a sound knowledge of the local environment has been acquired, a comparison can be made between different villages and towns in order to discover the influences which determine, for example, the growth of a particular industry and the type of employment thus created.

Elementary economics or principles of local government can legitimately be included.

In urban schools, when the syllabus is being built up, reference may be made to the Municipal Departments which control the supplies of water, gas and electricity, and the disposal of sewage. These are not only excellent examples of the benefit of Science to the community, but, as future tax- and rate-payers, the children should be interested in them. Most large towns have factories which are willing to supply helpful material to the school. Lessons in crystallization are just as well based on examples from salt mines, sugar refineries or soda works as on the growth of potassium nitrate crystals. In smaller towns, it often happens that some special industry is prominent, and to this frequent reference should be made. Examples are afforded by the mining of coal and various ores, the manufacture of iron, steel and other metals, pottery and brick works, textile mills, soap works, the production of dyes, etc. Numerous scientific principles and applications are to be found in the management and processes of such industries, some of which have interesting histories connected with a particular discovery or national requirement.

In agricultural districts it is most important that the school work should be connected with the environment, and that Chemistry lessons should be linked with Biology, Physics and Physical Geography. The syllabus should include such topics as the composition of soil, artificial fertilizers, natural fertilizers, legumes, purification of water, acidity of the soil, simple tests on milk and butter, soap-making, weather records and yearly maps showing the yields of local crops, dates of harvesting and the system for rotation of crops.

Applications to elementary Chemistry.—It is possible to further the scientific study of the locality by utilizing the eagerness with which many boys make collections. Samples of minerals, rocks and sea-shells may be obtained; pamphlets, circulars and labels advertising food products often lend themselves to scientific discussion; plants and flowers which grow in specific parts of the neighbourhood provide suitable specimens. Each collection should be systematized, and the whole grouped under headings in preparation for further investigation.

A detailed study might be made of the neighbourhood, and the written details might be placed on a wall-newspaper, in a book or on a diagram. Large maps and charts might be drawn up to summarize the information, and pupils might prepare lectures to give to the school. Careful and neat records and references should be insisted upon. The subjects covered will all be connected with General Science rather than Chemistry as a separate subject, e.g. a simple geological survey including the local uses, if any, of sand, clay, limestone and coal; types of trees and plants and the soils they prefer; atmospheric pollution and its prevention; need for painting iron- and steel-work in the area, and prevention of rusting; rainfall of the area and comparison with other areas; human needs for pure air, water and food.

In some Science lessons the school itself might well be the starting-point for a special topic. A new fire-extinguisher, new cement-work, the electricity supply, metals and glass used in the school: all these involve scientific principles and applications which can be worked out in detail.

In other lessons, pupils may be asked to bring specimens and materials, e.g. a lesson on:—

alkalis	requires soap and washing-powder;
carbon dioxide	" egg-shells, sea-shells, baking-powder;
crystals	" alum and copper sulphate;
ammonia	" feathers, hoofs, horns, etc., smelling salts and sal ammoniac;
carbon	" tin lids, sawdust, coal and coke;
acids	" vinegar and tartaric acid;
indicators	" various flowers.

The discussion of the occurrence and uses of local minerals, and of the economic and geographical factors influencing the growth of towns or particular industries, are far too often neglected in junior Science courses. Processes connected with the making of soap, candles, paints, glass, textiles, tin-plate, brewing, flour, oil refining, shipping and agriculture provide occasional but invaluable starting-points for a more serious study of sections of Chemistry.

Thus school work is linked up with familiar home commodities, and the pupil realizes that Chemistry deals with substances which affect him and with which he is in daily contact.

A Science course for a coastal town

It is advisable to study the locality and its industries from a much wider aspect than that of Chemistry or even Science. Indeed, the geographical, historical, scientific and mathematical aspects might all be interwoven. The correlation of several subjects can be successfully worked out when considering local conditions. Thus, in the section dealing with Geography, lessons should be given on such subjects as the sea-bed, sea erosion, tides, currents, fisheries, influences affecting the climate, coral islands, transport and the Suez and Panama canals. History has scope with the evolution of ships, migration, settlement, naval battles, and the influence of the sea on national characteristics. The Physics syllabus might include the study of land and sea-breezes, specific heat of sea-water, buoyancy, the Plimsoll line, colour of sea-water and the penetration of light rays. Biology can be studied by means of seaweeds, algae, habits and structure of fish and sea animals, evolution, competition for life, dispersal of seeds by the sea, interdependence of plant and sea life, and the supply of food for human beings. Various types of handwork complete such projects. Photographs should be mounted, cuttings from newspapers and advertisements should be pasted in improvised scrap-books, and clay or plasticine replicas of non-permanent specimens should be fashioned. Scenic models of a local factory, and working models illustrating mechanical principles, should be constructed. Since many measurements and calculations are entailed in the making of the models, in the plotting of weather graphs over a long period, and in the making of a regional survey, it will be seen that sound training in Mathematics is given incidentally.

Projects connected with elementary Chemistry

School projects in Science can rarely be attempted on a large scale in schools in which pupils are prepared for an external examination, unless they are carried out in the pupils' spare time. In a few schools, however, well-designed project schemes are worked out by the pupils and teacher. For example, systematic collections of biological specimens are made, a series of mechanical models is constructed to illustrate scientific principles, and facts of industrial and economic interest are summarized by charts and maps.

Local supplies are the main feature of many exhibits, whilst others are centred round one subject such as 'power', 'water-supply' or 'coal'. For example, a group of pupils may decide to carry out research on 'power'. The following branches of the project might be included: reference to information in town and school libraries; historical accounts of Priestley's lens, Lavoisier's charcoal furnace, the spirit lamp, the Bunsen burner, and other sources of heat; the historical development of transport; hot-air engines; steam engines; gas engines; petrol engines; water-mills; dynamos; electric power-stations; the 'Grid-scheme'; railway engines; marine engines; aeroplanes and motor-cars; atomic energy. Such a project embraces most branches of the General Science course. It includes visits to local power-stations, and reference to the gradual improvement in the utilization of natural resources. It gives scope to pupils who are proficient with tools and to those with literary tastes. The chief advantages of such a project are that knowledge is derived from a large field, the interests of the pupil are utilized, and school subjects are correlated. Many projects of a similar type originate with the pupils, and they are always worth developing because the pupils' interest—the primary factor in sound educational teaching—is so keenly alive.

In many schools the project is attempted out of school hours, as time cannot otherwise be found for such investigation. Opportunity may occur in the slack time after terminal examinations, when pupils are staying on temporarily and have no examinations to view, or if old pupils come back to school volunteering to help in any work which is being done.

Further, these projects suggest one method in which the usual school work may be recast if examinations are ever abolished. Teachers could then provide their own schemes of work embracing

subjects of a much wider scope than those attempted today. The treatment of such material could be much less stereotyped, as it could be specially selected to suit the pupils.

The projects described in the following chapter are treated in some detail in order to emphasize the principles behind such schemes. These may require an experimental technique beyond the skill of a boy under sixteen years of age, but suggestions for more elementary work are given at the end of the chapter.

The rural environment in tropical areas

Although children should receive simple lessons on Science from an early age, primary schools seldom provide suitable courses. This is most unfortunate in rural areas where there is little industrial activity. The teacher of Chemistry whose pupils live in rural communities must spend much time in 'filling in the background'. During the first two or three years he may have to adapt the syllabus so that it covers the experiments and subject-matter which a class should have studied previously. He himself may have to read many simple books,¹ and he must certainly encourage his pupils to read widely on elementary Science. He will have to study the environment and find out simple lines of approach and appropriate material for his lessons.

At all stages a good teacher will try to relate his work to activities and substances known locally. Many scientific methods and principles can be taught and applied through an examination of various processes, and perhaps in attempts to improve them. Examples to be found in different localities include: (a) charcoal—types of wood and ovens, efficient burning; (b) wood ash—kinds of wood, uses, analysis, solubilities, plant-culture experiments; (c) manures; (d) pottery—clays, glazing materials, firing; (e) timber preservation; (f) purification of water; (g) rocks and minerals; (h) extraction of dyes from plants; (i) soap-making; (j) the preparation of medicines from plants.

¹ e.g. the first five volumes of this series.

CHAPTER XIV

School Exhibitions and Chemical Clubs

Necessary preliminaries

An exhibition of the type to be described provides many opportunities for attaining the ideal of co-operation between pupils, parents and staff. During this exhibition, friends and relatives walked round the laboratories in the two hours available, the boys and girls of the school having seen the exhibition earlier in the day.

In discussing how to stage the exhibition it was decided that dangerous experiments must be omitted, and that experiments which were working continuously would be most suitable. Suggestions were made by the pupils, and, where possible, the originator of a scheme carried it out. While some of the subjects treated were individual ones, others were more suitably developed as group-projects. Thus, demonstrations were centred round subjects such as coal and coal-gas, the town's water supply, sea-water, paints, and flavouring essences.

The pupils began the preparatory work by collecting information on their special subject from every available source. Notes on earlier school work and books from the school and public libraries were consulted. These details had to be obtained, as pupils were to act as guides to the visitors. In some cases, it was decided to enlist the aid of firms which supply illustrative material such as specimen cases, catalogues, films and working models. The skill of fellow pupils in metalwork, woodwork, drawing and printing was also utilized.

After sorting out the useful material and arranging it under suitable headings, experiments which were thought to be effective were tested. Some gave no trouble. They were spectacular, easily visible, emphasized the point in question, and were either continuous or could be repeated several times during the evening. Other experiments were definitely unsuitable, and improvements and changes had to be made before the experimenter felt confident of being able to satisfy a critical elder brother or sister when the exhibition took place. After several meetings, final arrangements were made. Two

senior pupils were elected as supervisors, and under their guidance the demonstrations were displayed to the best advantage on the laboratory benches. All the experiments and important laboratory fittings, such as fume-cupboards and hot-air ovens, were distinctly labelled and their uses briefly explained.

A project on coal

The most important exhibits were projects. One, on coal, began by showing a home-made turbine built in a biscuit-tin, with metal vanes driven by a jet of tap-water. This turbine supplied the power to drive a coal-conveyer across the room to a 'Meccano' coal-crusher and sorter. The powdered coal was then heated in a hard-glass test-tube, and it was shown that ammonium sulphate, coal-tar and coal-gas could be obtained by methods similar to those used industrially. Whilst senior boys showed how benzene and naphthalene could be extracted from coal-tar and converted step by step into aniline, diazonium compounds and aniline dyes, other pupils demonstrated the dyeing of cloth and the use of mordants. The applications of these coal-tar products was shown by a display of silks, cloths, sample cards of every colour, and coloured and perfumed sweets and bath salts. Large beakers were filled with dilute solutions of aniline dyes to illustrate the wide range of colours available. In addition, many of the raw materials obtained from coal-tar were shown. This portion of the project was completed by illustrative charts and cardboard models of a typical coal-gas plant and coal-tar distillation plant. Further experiments were connected with coal-tar. Improvised Bunsen burners, two feet high, were constructed (see Figure 6), and the principles involved in the use of the Davy safety-lamp were demonstrated. Coal-gas was passed through soap solution, and the lightness and inflammability of the gas was shown by igniting bubbles in mid-air. Coloured flames, typical of certain metallic radicals, were also shown. Lastly, the use of ammonium sulphate and its connexion with fertilizers, water cultures and Chile saltpetre were explained by descriptive charts, pamphlets and experiments.

A project on water

Water was another subject around which a series of exhibits was organized. Methods of purifying drinking water were illustrated by

distillation, sterilization and filtration through a model sand-filter. The importance of softening water was shown by running standard soap solution into medicine bottles containing the same volume of distilled, river-, tap-, lake- and sea-water. The distilled water gave a permanent lather very easily, while the sea-water formed thick curds and gave a lather only after the addition of much soap solution. Similar experiments with the same kinds of water after boiling, adding soda, borax and 'household ammonia', were also carried out, so that the figures obtained measured the temporary and permanent types of hardness. A local firm kindly lent a water-softening plant and several instructive charts and booklets. The school water was run through this softening plant, and its hardness was determined, before and after softening, by standard soap solution. A large card gave details of the source, the amount consumed daily, and the usual hardness of the local water. An improvised apparatus for the electrolysis of water, and a cardboard model of a still, were also shown. Many exhibits incidentally connected with water were on view. A complicated apparatus showed the use of an aspirator to measure the percentage of water vapour and carbon dioxide in air. Experiments with invisible ink and weather indicators were based on the change in colour of hydrated salts. Improvised filter-pumps and thermostat stirrers were driven by jets of water.

Other projects

Other interesting projects were based on paints, micro-chemistry and flavouring essences.

Spectacular exhibits of crystals are always popular, and their growth was in progress in different solutions. Larger specimens of crystals were mounted, and the shape of smaller ones was shown by a micro-projection apparatus. A large diagram illustrated the principle of this apparatus, and numerous photographs, enlargements and slides were made by the boys. A large lead 'tree' was grown by suspending an old Leclanché zinc rod in a gas-jar containing lead acetate solution, and smaller 'trees' of silver, copper and other metals were on view under microscopes and magnifying glasses.

Although Nature Study was taught only in junior classes, advantage was taken in this exhibition to show collections of local birds'

eggs, stuffed birds, and coloured sketches of biological interest. The importance of each was lucidly explained by the owners.

Individual demonstrations

Individual demonstrations may be described in less detail.

1. Electric writing with a sheet of blotting-paper soaked in sodium chloride solution and phenolphthalein, placed on a sheet of metal.
2. Manufacture of vinegar by souring of wine. Model of the industrial process shown.
3. Fermentation of sugar and rectification of alcohol.
4. Titration experiments with different indicators.
5. Distillation under reduced pressure.
6. Gas analyses.
7. 'Chemical conjuring.'
8. The purification of mercury by filtering and dropping through dilute nitric acid in a long glass tube.
9. A lino-cutting of the Egyptian hieroglyphics 'kemi' (Chemistry), and chart of drawings of historical value.
10. A 'robot' three-colour automatic regulator device to show increase or decrease in weight.
11. 'Meccano' and other models showing improvised test-tube racks, shaking and stirring apparatus, and various stands.
12. Exhibition cases of ores, metals, corals, drugs, sugar-cane.
13. Silica 'water-gardens'.
14. Loaned nickel exhibits and examples of nickel plating.

Many other examples of suitable experiments for an 'Open Evening' are given in *The Science Masters' Book*, the *School Science Review*, and many other books and journals. Much physical apparatus could also be legitimately shown. This might include the use of the dark-room to display lantern slides, X-ray and neon tubes, and of the episcopic to show pictures of historical apparatus and photographs of eminent scientists. Other spectacular apparatus might include an arc lamp (made from scrap material and with home-made resistances) and film-strip projector in action and other electrical apparatus.

It should be realized that the majority of parents are unfamiliar with chemical apparatus, and that the bending of glass tubing or blowing of glass bulbs, especially if done by their own child, is a source of great interest.

Advantages of an exhibition

The advantages of such an exhibition are many. Friends and old pupils make one of their few visits to the school. Parents informally discuss their child's progress and also see how their contributions to the rates and taxes are spent. Adults are attracted by the utilitarian aspect of Science, which may well be a starting point for more serious study. It is not unusual for a parent to begin the study of Chemistry at the same time as his son.

A boy who is weak in academic subjects may occasionally be above the average in constructive work. His interest is aroused and his energies are often directed towards the theoretical side of Chemistry when he is allowed to build up his own models for exhibition purposes. This is especially true when he can construct a model beyond the skill of his more academic classmates. On the other hand, the brilliant pupil who is often neglected is able to show his capabilities. He can strike out on new lines and prepare his exhibit with an individuality typical of his powers.

The collection of explanatory notes on the demonstration, the wide field of questioning from the visitors, and the attempts of the pupil to explain his model to a small crowd of interested people are an education for all concerned.

Exhibits

Parents, old pupils and friends are usually willing to co-operate in supplying different samples and unusual exhibits. These should be kept in glass-fronted cases. The following list might be useful to a teacher in selecting useful material:—

1. Samples of labelled minerals—particularly those of local or national interest. The local geological department of the area should be asked to supply labelled sets of minerals.
2. Typical crystals—quartz, sulphur, copper sulphate and different alums. Some of these may be grown in the laboratory, gummed on the head of a large pin which is stuck into a cork and covered by a test-tube.
3. Unusual minerals—coral, stalactite, stalagmite.
4. Different samples of metals and their alloys, illustrating their physical properties and uses in industry.
5. Old Chemistry books, prints, pictures, apparatus.

6. Unusual photographs—photographs of modern equipment, industrial plant, microphotographs of crystals.

7. Links with local or national industries—plastics, glass, textiles, dyes, soap.

8. Working models or stationary models—section of lead pipe showing deposit of calcium salts, model of gas-works or iron furnace.

School exhibitions and museums will only be of educational value if the samples are

- (i) clearly labelled,
- (ii) neatly and effectively arranged,
- (iii) attractive,
- (iv) easily seen or accessible,
- (v) definitely linked to the pupil's interests,
- (vi) changed from time to time.

Curators of local museums, librarians, local experts in Chemistry, and local firms should be consulted whenever possible to help in arranging special displays.

Chemical clubs

A school Science society or club, with or without a distinct Chemistry section, is an out-of-school activity to be encouraged in every way. Such a club is essential in places where a tradition of 'bookish learning' must be broken, for it makes possible much practical work that cannot be done in school hours. Enthusiastic teachers are enabled to guide their pupils to deeper and wider studies.

Expeditions and exhibitions, such as those already described, provide a stimulus; lectures by staff or visitors supply variety to the club's programme; but the chief interest should lie in the members' own activities at regular meetings. Individual pupils can prepare papers and demonstrate experiments, and groups can carry out projects and investigations. (Results and conclusions often prove to be invaluable as a basis for formal class lessons.) In addition to the many suitable topics mentioned previously, such subjects as the following may be studied: (a) insecticides; (b) rubber; (c) fermentation processes; (d) metallic corrosion; (e) foodstuffs—cooking, preservation. Such studies should always be centred upon local materials and conditions.

CHAPTER XV

The Design of a Chemistry Laboratory

General principles

The design will depend, to a large extent, on whether an existing room is to be converted, or a new building is to be erected, for use as a laboratory. In many schools, Chemistry will be taught as part of the course in the General Science laboratories, and there will be no need for a junior laboratory specially designed for Chemistry. In schools with more than about three hundred pupils it is advisable to have one room with a definite bias towards Chemistry. These larger schools usually offer an advanced course, and pupils in the age-group 16 to 19 then require a separate advanced laboratory.

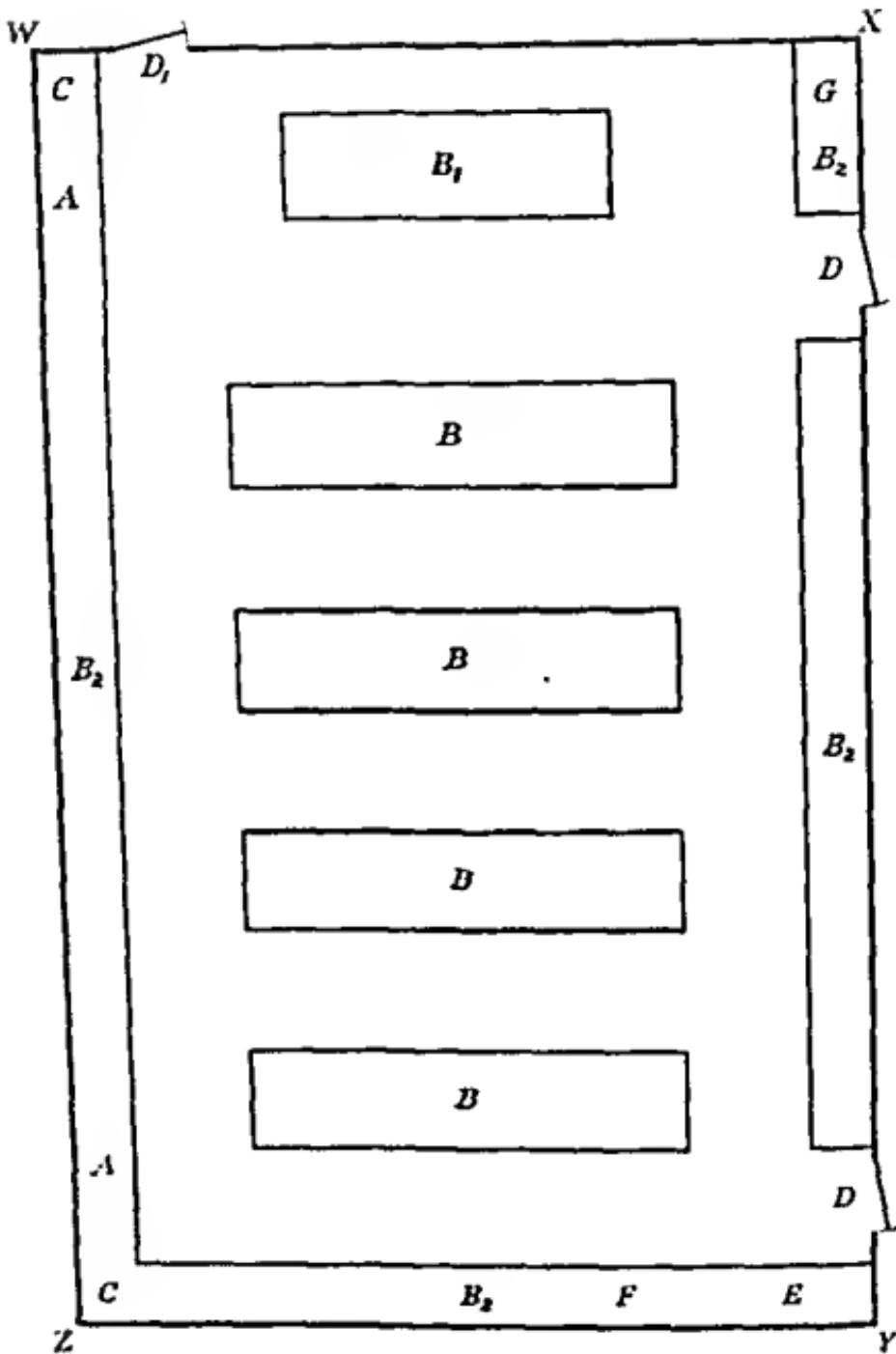
It is best to include the Chemistry laboratory with the other science rooms in one wing of the school buildings, and close to the wood- and metal-work rooms. The Chemistry laboratory should be sited so that the risk of unpleasant smells penetrating to other rooms or buildings is reduced to a minimum.

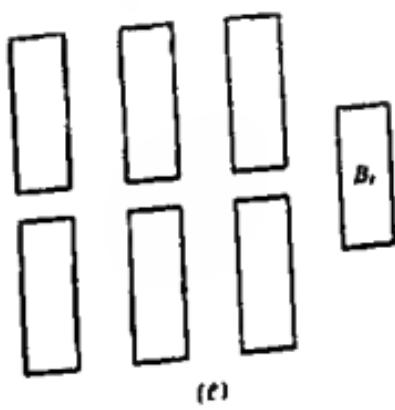
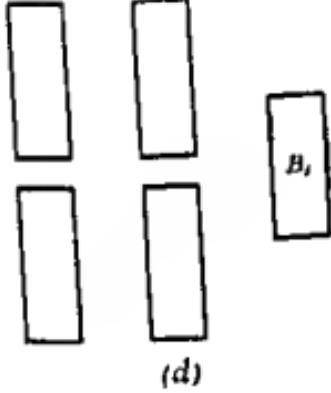
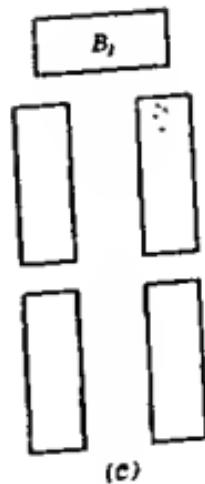
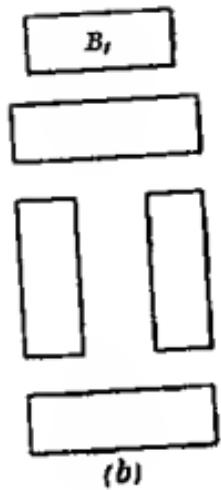
A lecture-room, adjoining the laboratories, is a great asset in a large school. More important, however, is the provision of suitable preparation-, store-, and balance-rooms.

Lighting, ventilation and, in cold countries, heating must be efficient. Arrangements will depend upon local conditions, but some features are universally applicable: e.g. doors and windows should open outwards; there should always be light coming from the pupil's left; each laboratory should have two main exits. Precautions against fire should never be overlooked.

Some details

Architectural style, building materials, etc., will be governed by local circumstances, but the basic aim must be to provide the most suitable rooms for the practice, learning and teaching of Chemistry. For example, a verandah along at least one side of the room is desirable in tropical countries, but care must be taken to ensure that the pillars which support the roof are built so that they do not obscure





the windows and reduce the light. Similarly, steel-framed windows are often fitted to open inwards, thus wasting valuable bench or storage space in a laboratory. A few more considerations may be mentioned:—

Walls.—Chemical fumes rapidly discolour lead paints, which should never be used, therefore, on laboratory walls. There should be at least one large notice-board; and wooden frames, or parallel laths nailed to the walls, are useful for display purposes on surfaces of plaster, cement, brick, etc.

Roof and ceiling.—In the tropics it is important that these should give adequate heat insulation. The roof should have enough 'overhang' to cut out most of the direct sunlight.

Floor.—A wooden floor is preferable, but it is expensive, must be waterproofed in the case of an upstairs room, and must be kept free from termite attack. A slight slope is useful, in case of the accidental spilling of liquids. Easy access to drainage channels, and all pipes and wiring, is essential.

Doors.—These should be at least 4 feet in width, so the double type is to be recommended. Doors opening on to verandahs should have the upper halves made of glass panels.

Windows.—In tropical conditions these are usually kept wide open. Unless they are of the sash type, it is advisable to have the bottom part (say 18 inches) fixed, in order to prevent undue interference by draughts with Bunsen flames, etc. It is usual to have plenty of windows in the long walls of the laboratory, to admit as much diffused light as possible: if direct light is not sufficiently reduced by eaves or verandah, canopies should be fitted.

Drainage.—Sink outlets should be connected to wide, straight pipes, as short as possible, leading to the main drainage channels. The latter are best made of glazed earthenware: e.g. ordinary drain-pipes cut in half along their lengths and embedded in concrete. They

should be covered by wooden boards, readily movable and flush with the floor.

Fume-cupboards.—It is useful to have one built behind the demonstration bench, alongside the blackboard. It is not essential to have others in a junior laboratory, particularly when there are verandahs on which improvisations can be arranged. If other fume-cupboards are required, they may be built in front of windows on the side of the room away from the prevailing wind. A cupboard should be about 2 feet deep and at least 3 feet square. It should be constructed of thick, transparent glass, with corrosion-proof base. The controls for water, gas and electricity must be outside the cupboard, and any internal piping, etc., should be coated with bitumen paint. The flue and outlet-pipe must be wide and similarly protected. An exhaust fan is necessary, and it should be of the high-speed, non-corrosive type manufactured for the purpose.

The junior laboratory

Dimensions.—An area of 1,000 square feet is satisfactory for a class of thirty pupils. The usual ratio of length to breadth is about five to three, and a room of approximately 40 feet \times 25 feet is therefore suitable.

Lay-out.—Benches must be arranged so that every pupil can see the blackboard and demonstration bench clearly. The teacher should be able to reach quickly the place of any pupil at any bench. Possible arrangements are suggested in the sketch plans in Figure 45. Water, gas and electric points, and reagent bottles, should all be readily accessible to each pupil.

Benches.—The tops should be of hard wood, about $1\frac{1}{2}$ inches thick, and should project at least 2 inches at the edges. A strip of white glass, or thick glass painted white on the under-surface, should be let into the tops of pupils' benches, down the centre, to carry reagent bottles. Bench shelving is not recommended. Bench tops should be preserved by regular treatment: with paraffix wax (ironed in), or beeswax dissolved in methylated spirits, or raw linseed oil; acid-proof liquids may also be used.

the windows and reduce the light. Similarly, steel-framed windows are often fitted to open inwards, thus wasting valuable bench or storage space in a laboratory. A few more considerations may be mentioned:—

Walls.—Chemical fumes rapidly discolour lead paints, which should never be used, therefore, on laboratory walls. There should be at least one large notice-board; and wooden frames, or parallel laths nailed to the walls, are useful for display purposes on surfaces of plaster, cement, brick, etc.

Roof and ceiling.—In the tropics it is important that these should give adequate heat insulation. The roof should have enough 'overhang' to cut out most of the direct sunlight.

Floor.—A wooden floor is preferable, but it is expensive, must be waterproofed in the case of an upstairs room, and must be kept free from termite attack. A slight slope is useful, in case of the accidental spilling of liquids. Easy access to drainage channels, and all pipes and wiring, is essential.

Doors.—These should be at least 4 feet in width, so the double type is to be recommended. Doors opening on to verandahs should have the upper halves made of glass panels.

Windows.—In tropical conditions these are usually kept wide open. Unless they are of the sash type, it is advisable to have the bottom part (say 18 inches) fixed, in order to prevent undue interference by draughts with Bunsen flames, etc. It is usual to have plenty of windows in the long walls of the laboratory, to admit as much diffused light as possible: if direct light is not sufficiently reduced by eaves or verandah, canopies should be fitted.

Drainage.—Sink outlets should be connected to wide, straight pipes, as short as possible, leading to the main drainage channels. The latter are best made of glazed earthenware: e.g. ordinary drain-pipes cut in half along their lengths and embedded in concrete. They

should be covered by wooden boards, readily movable and flush with the floor.

Fume-cupboards.—It is useful to have one built behind the demonstration bench, alongside the blackboard. It is not essential to have others in a junior laboratory, particularly when there are verandahs on which improvisations can be arranged. If other fume-cupboards are required, they may be built in front of windows on the side of the room away from the prevailing wind. A cupboard should be about 2 feet deep and at least 3 feet square. It should be constructed of thick, transparent glass, with corrosion-proof base. The controls for water, gas and electricity must be outside the cupboard, and any internal piping, etc., should be coated with bitumen paint. The flue and outlet-pipe must be wide and similarly protected. An exhaust fan is necessary, and it should be of the high-speed, non-corrosive type manufactured for the purpose.

The junior laboratory

Dimensions.—An area of 1,000 square feet is satisfactory for a class of thirty pupils. The usual ratio of length to breadth is about five to three, and a room of approximately 40 feet \times 25 feet is therefore suitable.

Lay-out.—Benches must be arranged so that every pupil can see the blackboard and demonstration bench clearly. The teacher should be able to reach quickly the place of any pupil at any bench. Possible arrangements are suggested in the sketch plans in Figure 45. Water, gas and electric points, and reagent bottles, should all be readily accessible to each pupil.

Benches.—The tops should be of hard wood, about $1\frac{1}{2}$ inches thick, and should project at least 2 inches at the edges. A strip of white glass, or thick glass painted white on the under-surface, should be let into the tops of pupils' benches, down the centre, to carry reagent bottles. Bench shelving is not recommended. Bench tops should be preserved by regular treatment with paraffin wax (ironed in), or beeswax dissolved in methylated spirits, or raw linseed oil; acid-proof liquids may also be used.

(i) The *demonstration bench* should be placed in front of a blank wall of the laboratory, on a platform 9 inches high. It should be about 10 feet in length (preferably with hinged extensions at the ends), 3 feet high and 3 feet wide. There should be 6 inches of toe space on the teacher's side, and a recess for knees and to hold a stool or chair. The interior of the bench should consist of suitable cupboards and drawers. The following services are suggested:—(a) Sinks with water-taps, each sink $12 \times 9 \times 9$ inches. If one sink is fitted with a glass front, it may be used as a pneumatic trough visible to the class. (b) Three separate gas points with taps. (c) Two ordinary and two low-voltage electric points. The passage-way in front of the bench should be at least 5 feet wide so that the class can be brought close when required.

(ii) The *pupils' benches* should be separated by gangways of 4 feet in width. The 'island' type is most suitable: 12 feet in length, 3 feet high, and 2 or 4 feet wide respectively for single and double benches. Six inches of toe space is advisable, and also knee room between lockers or cupboards. Some teachers are in favour of pull-out flaps to provide space for note writing. Sinks with water-taps should be situated near each end of each bench. Four pairs of gas points are required.

(iii) There should be as many *side benches* as possible along the walls; 2 feet is a suitable width. The space underneath is useful for storage, and shelves, drawers or cupboards may be fitted as needed. They should include two large sinks, one with a hot-water supply. Appropriate parts of the side benches must be reserved for still, ovens, blowpipe work, etc., the surfaces of these parts being covered by asbestos sheets.

Cupboards and lockers.—Most chemical apparatus, especially glass-ware, is best kept under cover rather than on open shelves. Thus there must be ample cupboard space. Bench lockers are convenient in some ways, but have their disadvantages. Everything depends upon the method of organization of practical work: e.g. trays containing pupils' sets of apparatus can quite well be kept in cupboards under side benches, if the latter are suitably situated. Cupboard doors should be of simple design and should fit well, in order to keep out dust and insects as far as possible. A wall cupboard behind a sliding blackboard is very useful to the teacher.

Stools.—Some teachers, who rightly regard the laboratory as a place for the performance of experiments, consider seats to be unnecessary. The majority prefer to have stools, kept under the benches when not in use. The stools should be of different heights (say 21 to 24 inches) to suit pupils of various heights. Rubber studs, screwed to the feet of the stools, help to reduce noise and wear. Nowadays some teachers prefer steel-framed chairs of the type which is easily stacked.

Blackboard.—The blackboard, behind the demonstration bench, must be as large as possible. The sliding type, or one of revolving cloth, is convenient. The most satisfactory surface, however, is ground glass, painted green or black at the back. If space can be found, it is useful to have a supplementary blackboard placed half-way along a side wall.

Space behind the blackboard can be used for cupboards, the teacher's reagent shelves, storage of gas-cylinders, etc., or can be arranged for projection from the rear of the screen. A shelf for reference books and a frame for holding and displaying charts should be fitted near the blackboard.

The advanced laboratory

Many of the suggestions for the junior laboratory are equally applicable to an advanced Chemistry laboratory. There will be a smaller number of students in the latter case, and they will usually work individually. An area of 500 square feet is found to be ample.

The following points should be borne in mind:—

- (a) On account of the organic work, more and larger fume-cupboards will be required.
- (b) Benches should be fitted with individual lockers and drawers.
- (c) More low-voltage electric points will be required.
- (d) The average height of stools must be greater.
- (e) The advanced laboratory will need more reagent shelves than the junior. There is less objection to having them along the centre of a bench.
- (f) Additional equipment is necessary: e.g. a blowpipe table; electric, muffle and combustion furnaces, with hoods, etc.

The mains services

In a General Science laboratory the supply of water, gas and electricity is often limited to the side benches. In a Chemistry laboratory they are needed on the main benches as well.

Water.—Laboratory work is difficult without a mains supply of water. In schools which arrange their own supply, the tanks should be placed as high as possible in order to obtain a good pressure. (Filter pumps do not work well at less than 30 lb. per square inch.) It is usual to have three taps to a sink, the central one being 'swan-necked' for use with long tubes such as burettes. Taps should be tapered and ridged, for the fitting of rubber tubing. They should be made of oxidized gun-metal, *not* chromium plate. It is advisable to have a separate control cock for each bench. The sinks in the demonstration and main benches should be fitted with wooden covers, flush with the bench tops, and having finger holes for easy removal. A suitable size is $12 \times 9 \times 9$ inches, but the sinks in the side benches should be larger: say $20 \times 16 \times 6$ inches.

Gas.—Coal-gas is unavailable in many places, and schools then require a petrol-air gas plant for the Science laboratories. Such a plant can be driven by falling weights in districts where there is no supply of electricity. Care must be taken to order the right kind of piping, fittings and Bunsen burners for the particular type of plant. For safety and economy it is best to have separate control cocks for each laboratory and each bench. Gas taps should be of robust design, made of oxidized gun-metal, in groups of four on the main benches. (Some teachers prefer to have the taps fitted under the front edges of the benches, but this is not very suitable for petrol-air gas.)

Electricity.—This is the least important of the mains services, but, if possible, points should be installed as suggested above. Further points (plugs) are needed over the side benches: e.g. for apparatus such as hot plates, ovens, stills, etc., especially in an advanced laboratory. Laboratory work at night makes electric light essential. Lamps should be at ceiling level, each with its own switch, and any metal parts should be protected from fumes. Fluorescent tubes are probably the most satisfactory form of lighting, but expert advice is

needed to ensure that they are fitted in the right places for particular purposes.

The preparation-room

This ranks next in importance to the laboratory. It is almost essential for the teacher and laboratory assistant; it can be used at times by senior pupils; it may even take the place, if large enough, of an advanced laboratory. Thus the preparation-room must be equipped with benches, cupboards, shelving, sinks and all services. One room may serve two laboratories, and it can be fitted with service hatches. Size and design will depend upon the intended purposes of the room, but the minimum area will be about 300 square feet.

The store

The store may be part of the preparation-room, if suitable space and shelving, etc., are available. In districts where there is much dust and insect life, it is advisable to use cupboards rather than shelves for the storage of apparatus, whether the store is a separate room or not. In any case it is useful to have a small separate store for chemicals.

The balance-room

The usual design is a long narrow room with benches, 15 inches wide, 36 inches above floor level, and free from vibration, along the sides. Sometimes a side of the preparation-room or the store is used for the balances. Some teachers prefer to keep all their pupils in sight, so arrange the balances on side benches, or in wall recesses, or in firm cupboards, in the laboratory.

The lecture-room

This may be regarded as a luxury in a small school, but it becomes almost a necessity in a large school. An area of about 600 square feet is needed for fifty pupils, i.e. for two classes to be present at the same time. If seats are arranged in tiers, a 5-inch step between each row is sufficient, and no platform is required. A demonstration bench, similar to that in the laboratory, must be fitted and must have all the mains services. A good lecture-room will be provided with fume-cupboard, reagent shelves, apparatus cupboards, 'visual-aid' arrangements, reference books, etc.

APPENDIX A

Important Names and Dates in the Development of Knowledge of Atomic Energy

1896 Becquerel discovered natural radioactivity
1897 Thomson discovered the electron
1898 X-rays and gamma-rays studied
1902 Soddy put forward the theory of spontaneous disintegration
1904 Rutherford discovered alpha-particles
1905 Einstein advanced the theory of relativity (and later showed
that matter and energy are interconvertible)
1912 Wilson detected nuclear particles (cloud-chamber experi-
ments)
1912 Thomson discovered isotopes of neon
1913 Moseley worked on X-ray spectra
1913 Hevesy and Paneth used radioactive indicators
1919 Rutherford transmuted nitrogen
1919 Aston used the mass spectrograph
1919
-23 Rutherford and Chadwick transmuted more elements
1932 Cockcroft and Walton transmuted lithium using electrically
accelerated protons
1932 Urey and Washburn discovered heavy hydrogen
1932 Chadwick discovered the neutron
1932 Lawrence described the cyclotron
1932 Anderson discovered the positron
1934 Curie and Joliot produced artificial radioactivity
1934 Fermi bombarded elements with neutrons
1938 Han and Strassmann discovered uranium fission
1940 Urey suggested methods for the separation of isotopes of
heavy elements
1942 The first continuous nuclear chain reaction

- 1945 Large-scale production of plutonium. First nuclear explosion
- 1946 Synchrotron first operated in London. Radioactive isotopes available from atomic pile
- 1947 Berkeley cyclotron working

Note.—The above is a skeleton list, probably sufficient for school use. It could, of course, be expanded and extended greatly.

References.—*Atomic Energy and the Physical Sciences.* Atomic Energy Commission, 1950. U.S. Printing Office
Science at War. Crowther & Whiddington. H.M. Stationery Office, London
Source Book on Atomic Energy. Glasstone. Macmillan
Applied Nuclear Physics. Pollard & Davidson. Wiley
Science News 2. (Atomic Energy Number)

APPENDIX B

Books for the Chemistry Library

(F)—published in France (French language)

(G)—published in Great Britain

(U)—published in the United States of America

1. HISTORICAL

DOORLEY. *The Radium Woman: Madame Curie*. Heinemann (G)

FINDLAY. *A Hundred Years of Chemistry*. Duckworth (G)

FINDLAY. *The Spirit of Chemistry*. Longmans Green (G)

HOLMYARD. *Chemistry to the Time of Dalton*. Oxford University Press (G)

HOLMYARD. *Makers of Chemistry*. Oxford University Press (G)

LOWRY. *Historical Introduction to Chemistry*. Macmillan (G)

MOORE. *A History of Chemistry*. McGraw-Hill (U)

PARTINGTON. *A Short History of Chemistry*. Macmillan (G)

TILDEN. *Chemical Discovery & Invention in the Twentieth Century*. Routledge (G)

TILOEN. *Famous Chemists*. Routledge (G)

Various authors. *Alembic Club Reprints*. Livingstone (G)

2. GENERAL (including 'Readers')

AHRENS & others. *Living Chemistry*. Ginn (U)

BABOR & LEHRMAN. *General College Chemistry*. Crowell (U)

BIDDLE & BUSH. *Chemistry Today*. Rand McNally (U)

BRITTEN. *Chemistry, Life & Civilization*. Chapman & Hall (G)

BULL. *Chemistry of Today*. Seeley (G)

CARLETON & CARPENTER. *Chemistry for the New Age*. Lippincott (U)

DULL & others. *Modern Chemistry*. Holt (U)

ELDER & others. *A Textbook of Chemistry*. Harper (U)

FINDLAY. *Chemistry in the Service of Man*. Longmans Green (G)

GAINER & others. *Introduction to Modern Chemistry*. Mosby (U)

GIBSON. *Chemistry & its Mysteries*. Seeley (G)

HEYNS. *Chemistry Experiments at Home for Boys*. Harrap (G)

HILDEBRAND. *Principles of Chemistry*. Macmillan (U)

HOPKINS and others. *Chemistry & You*. Lyons & Carnahan (U)

JAFFE. *New World of Chemistry*. Silver Burdett (U)

KENDALL. *Young Chemists & Great Discoveries*. Beil (G)

MCFIERNAN & others. *Chemistry at Work*. Ginn (U)

MIAUL. *Chemistry, Matter & Life*. Arnold (G)

PARTINGTON. *Everyday Chemistry*. Macmillan (G)

PHILIP. *The Romance of Chemistry*. Seeley (G)

RAWLINS & STRUBLE. *Chemistry in Action*. Heath (U)
 TANLING. *General Chemistry*. Freeman (U)
 Various authors. *Background Science Series*. Nelson (G)
 Various authors. *Common Commodities & Industry Series*. Pitmans (G)
 Various authors. *Science & Everyday Life Series*. Pitmans (G)
 Various authors. *Van Nostrand's Chemical Annual*. Van Nostrand (U)
 WEAVER & FOSTER. *Chemistry for our Time*. McGraw-Hill (U)

3. ELEMENTARY TEXT-BOOKS

BAYLES & MILLS. *Basic Chemistry*. Macmillan (U)
 BISHOP & LOCKET. *An Introduction to Chemistry*. Oxford University Press (G)
 BISHOP & LOCKET. *An Elementary Chemistry*. Oxford University Press (G)
 CHÂTELET. *Chimie 1re à 2e*. Baillière (F)
 GODDARD & HUTTON. *A School Chemistry for Today*. Longmans Green (G)
 HEYS. *New Introduction to Chemistry*. Hartap (G)
 HOGG and others. *Chemistry, a Course for High Schools*. Van Nostrand (U)
 HOLDerness & LAMBERT. *School Certificate Chemistry*. Heinemann (G)
 HOLMYARD. *Chemistry for Beginners*. Dent (G)
 LAUWERYS & ELLISON. *Chemistry*. University of London (G)
 LITTLER. *Elementary Chemistry*. Bell (G)
 MEE. *A Modern Chemistry for Schools*. Dent (G)
 RUMEAU & BERTRAND. *Chimie 1re et 2e*. Delagrave (F)
 SHUTT. *Introductory Chemical Calculations*. University Tutorial Press (G)
 SUTCLIFFE. *Elementary Chemistry*. Murray (G)

4. ADVANCED TEXT-BOOKS

(i) Inorganic

ADLAM & PRICE. *A Higher School Certificate Chemistry*. Murray (G)
 DURANT. *General & Inorganic Chemistry*. Longmans Green (G)
 EPHRAIM. *A Text-book of Inorganic Chemistry*. Gurney & Jackson (G)
 GODDARD. *Higher Chemical Arithmetic*. Longmans Green (G)
 HOLDerness & LAMBERT. *A Class-book of Problems*. Heinemann (G)
 HOLMYARD. *A Higher School Certificate Inorganic Chemistry*. Dent (G)
 LDWRY & CAVELL. *Intermediate Chemistry*. Macmillan (G)
 MELLOR. *Comprehensive Treatise on Inorganic Chemistry*. Longmans Green (G)
 MELLOR. *A Modern Inorganic Chemistry*. Longmans Green (G)
 PARTINGTON. *General & Inorganic Chemistry for University Students*. Macmillan (G)
 PARTINGTON. *Text-book of Inorganic Chemistry*. Macmillan (G)
 PHILBRICK. *Inorganic Chemistry*. Bell (G)
 PHILBRICK & others. *A Text-book of Theoretical & Inorganic Chemistry*. Dent (G)

PRESCHER, *Intermediate Chemistry: Inorganic & Physical*. Macmillan (G)
 QUELET, *Précis de Chimie*. Presses Universitaires (F)
 SHERWOOD TAYLOR, *Inorganic & Theoretical Chemistry*. Heinemann (G)

(ii) Physical

FINDLAY, *Introduction to Physical Chemistry*. Longmans Green (G)
 GODDARD & JAMES, *The Elements of Physical Chemistry*. Longmans Green (G)

HEYNS, *Physical Chemistry*. Harrap (G)

LOWRY & SUGDEN, *Physical Chemistry*. Macmillan (G)

MEE, *Physical Chemistry*. Heinemann (G)

SMITH, *Advanced Chemical Calculations*. Macmillan (G)

SUTCLIFFE, *Physical Chemistry*. Murray (G)

TIAN, *Notions fondamentales de Chimie Générale et de Physico-chimie*. Masson (F)

(iii) Organic

DURANT, *Organic Chemistry*. Longmans Green (G)

GRIGNARD, *Précis de Chimie Organique*. Masson (F)

HOLMYARD, *An Introduction to Organic Chemistry*. Arnold (G)

KEMP, *Elementary Organic Chemistry*. Dent (G)

MEE, *Organic Chemistry*. Dent (G)

NEWBURY, *A Concise Organic Chemistry*. Harrap (G)

PERKIN & KIPPING, *Organic Chemistry*. Chambers (G)

SCHMIDT, *Organic Chemistry*. Gurney & Jackson (G)

SHERWOOD TAYLOR, *Organic Chemistry*. Heinemann (G)

5. PRACTICAL

AMES & JAFFE, *Laboratory & Workshop Units in Chemistry*. Silver Burdett (U)

ARTHUR & SMITH, *Semi-micro Qualitative Analysis*. McGraw-Hill (U)

AUGER, *Les Principes de l'analyse chimique*. Le Francois (F)

BABOR & LEHRMAN, *Laboratory Manual for General College Chemistry*. Crowell (U)

BELCHER & WILSON, *Qualitative Inorganic Micro-analysis*. Longmans Green (G)

BELL, *Modern Practical Chemistry*. Arnold (G)

BIDDLE & BUSIL, *Laboratory Manual for Chemistry Today*. Rand McNally (U)

BILTZ, *Laboratory Methods of Inorganic Chemistry*. Wiley (U)

CLOWES & COLEMAN, *Quantitative Chemical Analysis*. Churchill (G)

COHEN, *Practical Organic Chemistry*. Macmillan (G)

CORNAY, *Semi-micro Experiments in General Chemistry*. Ginn (U)

CUMMING & KAYE, *A Text-book of Quantitative Chemical Analysis*. Gurney & Jackson (G)

DULL & BROOKS, *Chemistry Workbook*. Holt (U)

ECKERT & others. *Discovery Problems in Chemistry*. College Entrance Book Co. (U)

ELDER & others. *Laboratory Manual for College Chemistry*. Ginn (U)

FINDLAY. *Practical Physical Chemistry*. Longmans Green (G)

FOWLER. *Workbook in Chemistry*. Ginn (U)

FOWLES. *Lecture Experiments in Chemistry*. Bell (G)

FOWLES. *Volumetric Analysis*. Bell (G)

HOPKINS & others. *Chemistry & You in the Laboratory*. Lyons & Carnahan (U)

LAMBERT & MUIR. *Practical Chemistry*. Heinemann (G)

LITTLER. *A Short Course of Practical Chemistry*. Bell (G)

MCGILL & BRADBURY. *Chemistry Guide & Laboratory Exercises, with Accompanying Tests*. Lyons & Carnahan (U)

MANN & SAUNDERS. *Practical Organic Chemistry*. Longmans Green (G)

MEE. *Practical Organic Chemistry*. Dent (G)

MEE. *Volumetric Analysis*. Dent (G)

PALMER. *Experimental Physical Chemistry*. Cambridge University Press (G)

RAWLINS & STRUBLE. *Chemistry in Action in the Laboratory*. Heath (U)

SUDBOROUGH & JAMES. *Practical Organic Chemistry*. Blackie (G)

SUTCLIFFE. *Practical Chemistry for Advanced Students*. Murray (G)

TREADWELL & HALL. *Qualitative Analysis*. Wiley (U)

TREADWELL & HALL. *Quantitative Analysis*. Wiley (U)

VAN PRAAG. *Practical Physical Chemistry*. Cambridge University Press (G)

VOGEL. *A Text-book of Practical Organic Chemistry*. Longmans Green (G)

VOGEL. *A Text-book of Qualitative Chemical Analysis*. Longmans Green (G)

VOGEL. *A Text-book of Quantitative Chemical Analysis*. Longmans Green (G)

WEAVER. *Laboratory Introduction to Chemistry*. McGraw-Hill (U)

WEISBRUCH. *Semi-micro Laboratory Exercises in High School Chemistry*. Heath (U)

WILSON. *An Introduction to Micro-chemical Methods*. Methuen (G)

6. PERIODICALS

<i>Chemical Age</i>	<i>Science et Vie</i> (F)
<i>Discovery</i>	<i>The Industrial Chemist</i>
<i>Fire</i>	<i>The Journal of Chemical Education</i>
<i>Revue scientifique</i> (F)	<i>The School Science Review</i>
<i>School Science & Mathematics</i>	<i>The Science Teacher</i>
<i>Science Monthly</i>	<i>The Scientific American</i>

APPENDIX C

List of Chemicals

The approximate quantities required annually in a school with classes of 25-30 pupils each (for the type of course suggested in this book) are indicated as follows:

Winchester quart ¹	W	500 g.	(IV)
5 Kg.	(I)	250 g.	(V)
2 Kg.	(II)	100 g.	(VI)
1 Kg.	(III)	50 g.	(VII)

(a) INORGANIC

Aluminium, metal, foil (V)	Arsenic oxide (V)
turnings (IV)	Barium chloride (III)
Aluminium chloride (IV)	Barium hydroxide (V)
Aluminium sulphate (VI)	Barium nitrate (V)
Ammonium acetate (IV)	Barium oxide (V)
Ammonium carbonate (III)	Bismuth chloride (VI)
Ammonium chloride (III)	Bleaching powder (III)
Ammonium chromate (IV)	Borax (III)
Ammonium hydroxide, 0.960 (4W)	Bromine (V)
Ammonium molybdate (V)	Calcium, metal, turnings (IV)
Ammonium nitrate (V)	Calcium acetate (V)
Ammonium oxalate (V)	Calcium carbide (III)
Ammonium persulphate (V)	Calcium carbonate, marble (I)
Ammonium sulphate (III)	Calcium chloride, granular (III)
Ammonium sulphide (III)	Calcium fluoride (VI)
Ammonium thiocyanide (VI)	Calcium hydroxide (II)
Antimony, metal (V)	

¹ A 'Winchester quart' (W. qt.) is an old measure (equal to about 3 litres or 5 pints), used by many firms in the sale of chemical liquids. Bottles of this size make excellent storage vessels for the laboratory.

Calcium monophosphate (V)	Iron oxalate, ferric (VI)
Calcium nitrate (V)	Iron oxide, ferric, (VI)
Calcium oxide (II)	ferrous (V)
Calcium sulphate (IV)	Iron sulphate, ferrous (III)
Carbon, charcoal, animal (III)	Iron sulphide, ferrous (III)
blocks (25)	
wood (III)	
Carbon disulphide (II)	Lead, metal, foil (III)
Carbon tetrachloride (II)	Lead acetate (III)
Chromium chloride (V)	Lead nitrate (III)
Chromium sulphate (V)	Lead oxide, di- (V)
Cobalt nitrate (V)	mon- (V)
Copper, metal, foil (V)	red lead (V)
turnings (V)	
Copper carbonate, cupric (V)	Lead sulphate (VI)
Copper chloride, cupric (V)	Magnesium, metal, powder (VI)
cuprous (V)	ribbon (VI)
Copper oxide, cupric (IV)	Magnesium carbonate (VI)
cuprous (V)	Magnesium chloride (VI)
Copper nitrate, cupric (IV)	Magnesium oxide (V)
Copper sulphate, cupric (II)	Magnesium sulphate (V)
Hydrochloric acid,	Manganese chloride (V)
concentrated (4W)	Manganese dioxide (II)
Hydrogen peroxide (III)	Manganese sulphate (V)
Iodine (IV)	Mercury, metal (III)
Iron, metal, filings (III)	Mercury chloride, mercurie (VI)
wire (III)	mercurous (VI)
Iron alum, ferric (V)	Mercury nitrate, mercuric (VI)
Iron ammonium sulphate,	mercurous (VI)
ferrous (III)	Mercury oxide, mercurie (IV)
Iron carbonate, ferric (V)	mercurous (III)
Iron chloride, ferric (IV)	Methyl orange (VII)
ferrous (V)	Methyl red (VII)
Iron nitrate, ferric (V)	Methylated spirits (W)
	Nickel, metal, foil (VII)
	Nickel ammonium sulphate (VII)
	Nickel nitrate (VII)

Sulphur dioxide (I siphon)	Wool, glass- (V)
Sulphuric acid, concentrated (3W)	Zinc, metal, dust (V) soil (V) granulated (III)
Tin, metal, soil (IV)	Zinc chloride (VI)
Tin chloride, stannic (V) stannous (V)	Zinc nitrate (VI)
Tin oxide, stannic (V) stannous (V)	Zinc oxide (IV) Zinc sulphate (IV)

(b) ORGANIC

Acetaldehyde (IV)	Formalin (III)
Acetamide (IV)	Formic acid (V)
Acetanilide (IV)	Fructose (IV)
Acetic acid, glacial (W)	Glucose (IV)
Acetic anhydride (W)	Glycerine (W)
Acetone (W)	Methyl alcohol (III) (Methylated spirits) ¹
Acetyl chloride (W)	Methyl iodide (V)
Amyl acetate (W)	Naphthol, alpha- (V) beta- (V)
Aniline (W)	Nitrobenzene (W)
Benzaldehyde (W)	Oxalic acid (V)
Benzene (W)	Phenol (V)
Benzoic acid (IV)	Phenylhydrazine (VI)
Benzoyl chloride (V)	Picric acid (VI)
Benzyl alcohol (V)	Salicylic acid (V)
Bromobenzene (IV)	Starch, soluble (III)
(Carbon tetrachloride) ¹	Sucrose (III)
Chloroform (III)	Tannic acid (VI)
Citric acid (VI)	Tartaric acid (VI)
Ether, diethyl (W)	Toluene (V)
Ethyl acetate (W)	Urea (V)
Ethyl alcohol (W)	
Ethyl bromide (III)	

¹ See list (a).

APPENDIX D

List of Apparatus for the Chemical Laboratory

(a) JUNIOR

Asbestos mats (7.5 cm. & 18 cm. square)

Atomic model set

Balances (250 g.—sensitive to 10 mg.)

Balance, compression, with dial (5 Kg.)

Balances, spring (50 g. & 100 g.)

Basins, evaporating (120 ml. & 375 ml.)

Beakers, squat (250 ml. & 500 ml.)

Beakers, tall (150 ml.)

Beehive shelves (7.5 cm. diameter)

Bell-jars, ground flange (15 cm. diameter, 30 cm. height)

Blowpipes, mouth, 20 cm.

Bottles, ground-glass stoppers, narrow-mouthed, sand-blasted
labels ¹ (4 or 8 oz.—250 or 500 ml.)

Bottles, various (screw-top; wide-mouthed, etc.)

Brushes, burette

Brushes, test-tube

Burettes, with Mohr clips (50 ml.)

Burette racks

Burette stands

Burner, Bunsen

Burner, tube type

Clock glasses (10 cm. diameter)

¹ Ammonium acetate, carbonate, chloride, hydroxide, oxalate, sulphide;

Barium chloride;

Borax;

Fusion mixture;

Hydrochloric acid concentrated, dilute;

Lead acetate;

Lime-water;

Nitric acid concentrated, dilute;

Potassium hydroxide;

Silver nitrate (amber-coloured bottle);

Sodium carbonate, hydroxide, phosphate;

Sulphuric acid concentrated, dilute.

Cobalt-blue glasses (5 x 2 cm.)
Combustion boats, glazed porcelain
Combustion tubes, open ends (30 x 1.8 cm.)
Condensers, Liebig (40 cm., or double-surface 15 cm.)
Corks, bark (10 to 38 mm. diameter)—to fit apparatus in use
Cork shives (40 to 100 mm. diameter)
Crucibles, with lids (4 cm. diameter, 17 ml.)
Crucible tongs, nickel (15 cm.)
Cylinders, graduated (100, 250 & 500 ml.)
Deflagrating spoons, steel, with brass cap
Desiccators (10, 15 & 25 cm. diameter)
Desiccator jars, triangular, for balance cases
Dishes, crystallizing (70 mm. diameter, 50 mm. height)
Drying towers (4 x 20 cm. & 5 x 25 cm.)
Drying-tubes, calcium chloride, straight with bulb (12 x 1.5 cm.)
Files, round
Files, triangular
Filter papers (9 & 11 cm. diameter)
Filter pumps, chromium-plated
Filter stands
Flasks, conical (250 ml.)
Flasks, distilling (100, 250 & 500 ml.)
Flasks, flat bottom (250 & 500 ml.)
Flasks, graduated (100, 250, 500 & 1,000 ml.)
Flasks, round bottom (250 & 500 ml.)
Funnels, burette (5 cm. diameter)
Funnels, dropping (100 & 250 ml.)
Funnels, filter, short stem (7.5 cm. diameter)
Funnels, thistle (25 cm.)
Funnel stands, to take two funnels
Furnace, muffle, 1,000° C.
Gas jars, with ground covers (4 x 20 cm.)
Glass rod (3, 4, 5, 6 mm. diameter)
Glass tubing (4 to 25 mm. internal diameter)
Glass tubing, capillary (4 mm. external diameter)
Litmus paper, books (red, blue and neutral)
Mercury troughs
Mortars and pestles, porcelain (50 ml.)

Pipettes (10, 25 & 50 ml.)
 Retorts, glass, stoppered (100 & 250 ml.)
 Retort stands, with rings and clamps (45 cm. height)
 Rubber stoppers (16 to 25 mm. diameter; a few larger sizes)
 Rubber tubing (4 to 6 mm. internal diameter)
 Rubber tubing, Bunsen burner
 Rubber tubing, pressure (5 mm.)
 Sand baths (7 cm. diameter)
 Spatulas, horn—and a few nickel
 Specimeo tubes, with cap (25 x 50 mm.)
 Taps, glass (5 mm. bore)
 Test-tubes, boiling (2.5 x 15 cm.)
 Test-tubes, hard glass (1.6 x 12.5 cm.)
 Test-tubes, ignition (1 x 5 cm.)
 Test-tubes, soft glass (1.6 x 12.5 cm.)
 Test-tube holders
 Test-tube stands (5 holes & pegs)
 Thermometers (- 10 to + 110° C.)
 Tiles, white (10 x 10 cm.)
 Triangles, pipeclay (5 cm.)
 Tripods (correct height for Bunsen burners in use)
 Troughs, pneumatic, earthenware (30 cm. diameter, 12.5 cm. depth)
 Troughs, glass (30 x 22.5 x 20 cm.)
 U-tubes, drying, with side tubes (2 x 15 cm.)
 Water baths, with rings, aluminium (12.5 cm. diameter)
 Weighing bottles, with cap (25 x 50 mm.)
 Weights, boxes, for balances
 Wire gauzes (20-mesh, 12.5 x 12.5 cm.)

(b) ADVANCED

Aspirators (3 litre)
 Balances, analytical, with weights
 Balances, chemical, with weights (sensitive to 0.2 mg.)
 Boyle's law apparatus
 Burettes, with stopcocks (50 ml.)
 Cells, hydrogen electrode, etc.
 Centrifuge
 Charles's law apparatus

Crucibles, nickel
 Dumas's apparatus
 Flasks, filter (250 & 500 ml.)
 Forceps
 Fractionating columns
 Funnels, fritted
 Gas analysis apparatus, Hempel's
 Gooch crucibles
 Indicators, set
 Landsberger's apparatus
 Molecular weight apparatus, Beckmann's (thermometer in 1/100° C.)
 Nitrometer
 Pipettes (1 & 2 ml., graduated in 1/10 ml.)
 Porous pots (5 cm. diameter, 15 cm. height)
 Thermometers (0 to 110° and 360° C.; -10 to +50 × 1/5° C.)
 Victor Meyer's apparatus

(c) GENERAL

Accumulators (in the absence of a mains supply of electricity)
 Acid trays, porcelain
 Barometer, mercury (Fortin's)
 Bell-jars, stoppered
 Bench, workshop, with vice, etc.
 Blowpipe (with bellows, etc.)
 Buchner funnels
 Buckets
 Candles
 Chisels
 Cork borers (3 to 25 mm. bore)
 Cork-borer sharpener
 Cork-cutting knife
 Cork squeezer
 Cutter, glass-tubing
 Dusters
 Enamel, anti-corrosion
 Film-strip projector
 Fire equipment
 Funnel, enamelled

Funnels, glass (large)
Gas lighter
Glass cutter, diamond
Grease
Hacksaw
Hammer
Hot-air oven
Hot-water oven (may be incorporated in the still)
Insulating tape
Jugs, enamelled (also mugs, saucepans, etc.)
Jugs, stoneware
Kipp's apparatus
Magnets
Matches
Medicine bottles
Microscope
Micro-projector
Oil-can
Ozonizer
Paint
Paint brushes
Pincers
Pliers
Rulers
Sand-paper
Scoops, aluminium
Screwdrivers
Soldering set
Stencils, for labels
Still, distilled water (preferably including oven)
String
Stop-watch
Swabs
Tapers
Thermostat, water-bath, with stirrer
Tinman's snips
Towels
Voltameter, copper

APPENDIX D

Voltameter, nickel electrodes

Waste boxes

Winchester quart bottles

Wire cutters

Wooden splints

APPENDIX E

List of Suitable Contents for a First-Aid Cupboard

The first-aid outfit. — Bandages, adhesive plaster, lint, gauze, cotton-wool, slings, safety-pins, eye-bath, sterilized burn dressings, tannic acid jelly for burns, etc. (Solutions should be kept in distinctly labelled bottles.)

Acids. Vinegar (dose 1 oz. in a quarter of a tumblerful of water); citric acid (dose 20 grains in a quarter of a tumblerful of water); 1 per cent. solutions of acetic acid, boric acid (for eye-wash), and picric acid (for burns).

Borax. 1 per cent. (eye-wash).

Calcium carbonate. (Dose $\frac{1}{2}$ oz. stirred up in a quarter of a tumblerful of water. Repeat dose.)

Friar's balsam for capillary bleeding.

Iodine tincture. (2.5 g. iodine, 2.5 g. potassium iodide, dissolved in water, made up to 100 c.c. with alcohol.)

Lime-water.

Magnesium sulphate. (Dose $\frac{1}{2}$ oz. in 8 oz. of water.)

Milk of magnesia. (Dose $\frac{1}{2}$ oz. stirred with a quarter of a tumblerful of water.)

Mustard. (Dose one teaspoonful of mustard in 8 oz. of water.)

Olive oil as demulcent.

Sodium bicarbonate. (a) 1 per cent. eye-wash; (b) 5 per cent. solution.

Sodium chloride. (Dose one tablespoonful in tumbler of warm water.)

Sal volatile. (Dose one teaspoonful in glass of water.)

Sodium sulphate. (Dose $\frac{1}{2}$ oz. in 8 oz. of water.)

Tannic acid.

Vaseline.

Zinc sulphate solution. (Dose, as emetic, 30 grains in 8 oz. of warm water.)

APPENDIX F

Chemical Names and Formulae of Some Common Substances

Common (i.e. popular) name	Chemical name	Formula
Alabaster . . .	(A natural form of hydrated) calcium sulphate	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$
Alum	—See ammonia-alum, etc.	
Alumina	Aluminium oxide	Al_2O_3
Ammonia	Ammonia-(gas) (nitrogen trihydride)	NH_3
Ammonia	(Aqueous solution of ammonia and) ammonium hydroxide	NH_3OH
Ammonia-alum . .	Ammonium alum	$(\text{NH}_4)_2\text{SO}_4 \cdot \text{Al}_2(\text{SO}_4)_3 \cdot 24\text{H}_2\text{O}$
Ammonium hydrate . .	—See ammonia (solution)	
Animal charcoal . .	—See bone-black	
Anthracite	(A hard coal, as much as 97% carbon	C
Aqua fortis	(Concentrated) nitric acid	HNO_3
Aqua regia	(Mixture of concentrated) nitric and hydrochloric acids	— (HNO ₃ & HCl)
Arseniuretted hydrogen	Arsine; arsenic hydride (arsenic trihydride)	AsH_3
Baking-powder . .	(Mixture of) sodium bicarbonate and cream of tartar	
Baking-soda	Sodium bicarbonate	NaHCO_3
Black-lead	—See graphite	
Bleaching-powder . .	—See chloride of lime	
Blue vitriol	(Hydrated) copper sulphate	$\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$
Bone-black	(A mixture of about 90% and 10% of) calcium phosphate and carbon	
Borax	(Hydrated) sodium pyroborate	$\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$
Brass	(An alloy of) copper and zinc	— (Cu & Zn)
Brimstone	(Rott) sulphur	S

Common (i.e. popular) name	Chemical name	Formula
Brine	(Concentrated or saturated solution of) sodium chloride	NaCl
Bronze	(An alloy of) copper and tin	— (Cu & Sn)
Calamine	(A natural form of) zinc carbonate	ZnCO ₃
Calomel	Mercurous chloride	Hg ₂ Cl ₂
Cane sugar	Sucrose	C ₁₂ H ₂₂ O ₁₁
Carbide	Calcium carbide	CaC ₂
Carborundum	Silicon carbide	SiC
Caustic potash	Potassium hydroxide	KOH
Caustic soda	Sodium hydroxide	NaOH
Chalk	(A natural form of) calcium carbonate	CaCO ₃
Chile saltpetre	— See saltpetre	
China clay	— See kaolin	
Chloride of lime	(A mixture of) chiefly calcium hypochlorite and basic calcium chloride	—
Coal	(More than 60% of) carbon	C
Coal-gas	(A mixture of chiefly) hydrogen, methane and carbon monoxide	— (H ₂ , CH ₄ , & CO)
Coke	(Up to about 80% of) carbon	C
Common salt	— See salt	
Corrosive sublimate	Mercuric chloride	HgCl ₂
Corundum	(A natural form of) alumina) aluminium oxide	Al ₂ O ₃
Cream of tartar	Sodium hydrogen tartrate	NaC ₄ H ₄ O ₆
Diamond	(A natural form of) carbon	C
Duralumin	(An alloy of several metals with 94% of) aluminium	—
Dutch metal	(An alloy of about 80% and 20% of) copper and zinc	— (Cu & Zn)
Emery	(Impure corundum)	
Epsom salts	(Hydrated) magnesium sulphate	MgSO ₄ .7H ₂ O
Fire-damp	— See marsh-gas	

Common (i.e. popular) name	Chemical name	Formula
Flowers of sulphur	(A form of powdered) sulphur	S
Fluorspar	(A natural form of) calcium fluoride	CaF_2
Galena	(A natural form of) lead sulphide	PbS
Glass	(A mixture of chiefly) silicates of calcium and sodium or potassium	—
Glauber's salt . .	(Hydrated) sodium sulphate	$\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$
Glycerine	Glycerol	$\text{C}_3\text{H}_8\text{O}_3$
Grape sugar . . .	Fructose	$\text{C}_6\text{H}_{12}\text{O}_6$
Graphite	(A natural, and a manufactured, form of) carbon	C
Green vitriol . .	(Hydrated) ferrous sulphate	$\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$
Gypsum	(A natural form of hydrated) calcium sulphate	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$
Haematite	(A natural form of) ferric oxide	Fe_2O_3
Horn silver	(A natural form of) silver chloride	AgCl
Hypo (hyposulphite)	(Hydrated) sodium thiosulphate	$\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$
Industrial spirit .	(Mixture of wood spirit and 95% of) ethyl alcohol	$\text{C}_2\text{H}_5\text{OH}$
Iron alum	Potassium ferric alum	$\text{K}_2\text{SO}_4 \cdot \text{Fe}_2(\text{SO}_4)_3 \cdot 24\text{H}_2\text{O}$
Iron pyrites	Iron (ferrous) disulphide	FeS_2
Jeweller's rouge . .	Ferric oxide	Fe_2O_3
Kaolin	(A natural form of a) silicate of aluminium	$\text{Al}_2\text{H}_5\text{Si}_4\text{O}_10$
Laughing-gas . .	Nitrous oxide	N_2O
Lime	—See quicklime and slaked lime	
Lime-water	(A solution of) calcium hydroxide	$\text{Ca}(\text{OH})_2$
Limestone	(A natural form of) calcium carbonate	CaCO_3
Liquor ammoniae fortis	(Concentrated aqueous solution—S.G.: 0.880—of) ammonia and ammonium hydroxide	NH_4OH

Common (i.e. popular) name	Chemical name	Formula
Litharge . . .	Lead monoxide —See sal volatile	PbO
Lump ammonia . . .	Silver nitrate	AgNO ₃
Lunar caustic . . .	(Alloy of magnesium and other metals with 95% (of) aluminium	—
Magnalium. . .	Magnesium oxide (A natural form of) calcium carbonate	MgO
Magnesia . . .	Magnesium oxide	CaCO ₃
Marble . . .	(A natural form of) calcium carbonate	CH ₄
Marsh-gas . . .	Methane	C ₂ H ₅ OH
Methylated spirit . . .	(Wood spirit, other impurities, and 95% of) ethyl alcohol	NaNH ₄ HPO ₄
Microcosmic salt . . .	Sodium ammonium hydrogen (ortho)phos- phate	Ca(OH) ₂
Milk of lime . . .	(Suspension in aqueous solution of excess) calcium hydroxide	Mg(OH) ₂
Milk of magnesia . . .	(Aqueous suspension of) magnesium hydroxide	KNO ₃
Nitre . . .	Potassium nitrate	H ₂ SO ₄
Oil of vitriol . . .	(Concentrated) sulphuric acid	COCl ₂
Phosgene . . .	Carbonyl chloride	PH ₃
Phosphoretted hydrogen . . .	Phosphine; phosphorus hydride (phosphorus tribydride)	U ₃ O ₈ (CsSO ₄) ₂ ·H ₂ O
Pitchblende . . .	(A natural form of a) uranium oxide	
Plaster of Paris . . .	(Hydrated) calcium sulphate —See graphite	
Plumbago . . .	Potassium carbonate	K ₂ CO ₃
Potash . . .	Potassium alum	K ₂ SO ₄ ·Al ₂ (SO ₄) ₃ ·24H ₂ O
Potash alum . . .	(A mixture of chiefly) nitrogen and carbon	— (N ₂ & CO)
Producer-gas . . .	monoxide	— (formula not known)
Prussian blue . . .	Ferric ferrocyanide	HCN
Prussic acid . . .	Hydrocyanic acid	SiO ₂
Quartz . . .	(A natural form of) silicon dioxide	CaO
Quickslime . . .	Calcium oxide	Hg
Quicksilver . . .	Mercury	C ₂ H ₅ OH
Rectified spirit . . .	(10% of water with 90% of) ethyl alcohol	

Common (i.e. popular) name	Chemical name	Formula
Red lead . . .	Triplumbic tetroxide	Pb_3O_4
Red prussiate of potash	Potassium ferricyanide	$K_3Fe(CN)_6$
Rock ammonia . .	—See sal volatile	
Rock crystal . .	—See quartz	
Rock salt . . .	(A natural form of) sodium chloride	
Sal ammoniac . .	Ammonium chloride	$NaCl$
Sal volatile . .	(Chiefly) ammonium carbonate	NH_4Cl
Salt	Sodium chloride	— $((NH_4)_2CO_3$)
Salt-water . . .	(Aqueous solution of) sodium chloride	$NaCl$
Salt-petre . . .	Sodium nitrate	$NaCl$
Salt of lemon . .	Potassium quadroxalate	$NaNO_3$
Sand	(A natural form of) silica; silicon dioxide	$KH_3C_2O_4 \cdot 2H_2O$
Slaked lime . . .	Calcium hydroxide	SiO_2
Soda	—See washing-soda	$Ca(OH)_2$
Soda-lime . . .	Quicklime slaked by caustic soda solution	— $(Ca(OH)_2 \& NaOH)$
Soda-water . . .	A super-saturated aqueous solution of carbon dioxide	— $(CO_2 \& H_2CO_3)$
Spirits of salts . .	(Concentrated) hydrochloric acid	HCl
Sugar	—See cane sugar	
Sugar of lead . .	Lead acetate	$(CH_3COO)_2Pb$
Sulphuretted hydrogen	Hydrogen sulphide	H_2S
Tartar emetic . .	Potassium antimonyl tartrate	
Turnbull's blue . .	Ferrous ferricyanide	$KSbC_6H_5O_4$
Verdigris . . .	(Chiefly) basic copper carbonate	$Fe_2[Fe(CN)_6]_3$
Vinegar	(An impure, dilute solution of) acetic acid	— $(CuCO_3 \cdot Cu(OH)_2)$
Vitriol	—See oil of vitriol, blue vitriol, etc.	— (CH_3COOH)
Washing-soda . .	(Usually concentrated) sulphuric acid)	
Water-gas . . .	(Hydrated) sodium carbonate	$Na_2CO_3 \cdot 10H_2O$
	(A mixture of chiefly) hydrogen and carbon monoxide	— $(H_2 \& CO)$

APPENDIX F

Common (i.e. popular) name	Chemical name	Formula
Water-glass	(An aqueous solution of chiefly) sodium metasilicate	Na_2SiO_3
White lead	Basic lead carbonate	$2\text{PbCO}_3 \cdot \text{Pb}(\text{OH})_2$
White vitriol	(Hydrated) zinc sulphate	$\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$
Whitewash.	(Often describes a suspension of calcium hydroxide or calcium carbonate)	
Wood spirit	(Chiefly) methyl alcohol	CH_3OH
Yellow prussiate of potash	(Hydrated) potassium ferrocyanide	$\text{K}_4\text{Fe}(\text{CN})_6 \cdot 3\text{H}_2\text{O}$
Zinc blende	(A natural form of) zinc sulphide	ZnS

Index

Accidents: see 'First-aid'
Accuracy: see 'Errors'
Acids, precautions in storage of, 89
—, small-scale experiments with, 168
Air, 31
Aliphatic compounds, 40-46
Alkalies, experiments with, 121
Aluminium, oxidation of, 247
Ammonia, preparation of, 65
Apparatus, 32, 86-87, 108, 236-238, 283-288
—, cost of, 110
—, diagrams of, 218-225
—, improvised, 93-94, 98-103
—, Kipp's, substitute for, 243
—, small-scale, 157-175
—, storage & care of, 92-95
—, students', 96
—, unit fittings, 162
Arithmetic, chemical, 153-156, 186
Aromatic compounds, 44
Atomic energy, 51, 273
Atomic theory, 5, 177-178, 192-193
Atoms, 177

Balance-room, 271
Benches, 96, 267
Blackboard, 221, 225, 269
Books, list of, 275
Bunsen burner, lesson on, 60-61
Burns: see 'First-aid'

Calcium carbonate, experiments with, 107, 121, 168
Calculations, chemical, 150, 153-157
Carbon cycle, 80
Carbon dioxide, 107, 145
Carbonates, experiments with, 168
Castner-Kellner process, 230-232
Catalysis, 207, 246
Charis, making & use of, 43, 225-229, 253
Chemical arithmetic, 153-156, 186
Chemical clubs, 262
Chemical equilibrium, 190-192
Chemical names for common substances, 181, 292
Chemical terms, teaching of, 202-208
Chemical theory, teaching of, 176-197
Chemicals, 85-92
—, amounts of for experiments, 103-107
—, cost of, 109
—, dangerous, 108, 116-119
—, storage of, 88-90
Chemistry as a hobby, 15, 248-250
—, benefits from studying, 11
—, cultural value of, 6, 8, 11
—, descriptive, 176
—, history of, 1-5, 55, 275
—, laboratory: see 'Laboratory'
—, library, 88, 192, 275
—, limitations of knowledge in, 174
—, micro-, 139, 157-175
—, projects in elementary, 255, 258-262
—, pure & applied, 6
—, research, 195-197
—, small-scale, 139, 157-175
—, social implications of, 9-10
Chemistry, advanced, elementary, general, in General Science, inorganic, organic, physical: see 'Syllabus'
Chemistry teaching, aims & ideals in, 12-14
—, criticisms of, 16-19
—, for advanced students, 32-36
—, methods in, 33, 57-84, 120-137, 176-197
Coal, project on, 258
Coal-gas, experiment with, 64
Conservation of mass, law of, 4, 28, 138, 196, 249, 250
Copper, experiments with, 168, 171, 245
Correlation of subjects, 18, 66, 229, 252-253, 254
—of teaching with environment, 251-256

- Cost of chemicals, 109
- of experiments, 109-111
- Courses for non-specialists, 53-55
- Crystals, exhibition of, 259, 261
- Cupboards, 268
- Dalton plan, 58
- Danger with chemicals, 89, 111, 116, 118
 - in experiments, 116, 118
 - of fire, 113, 116
 - with gases, 108
- Dates in chemical history, 55, 273
- Definitions, 205-208
- Deliquescent substances, 90
- Demonstration bench, 268
- Demonstration methods, 120, 127-137
 - , advantages of, 128-129
 - , research on, 134-136
- Diagrams, 218
 - , errors in, 223-225
 - , sectional, 220-225
 - , text-book, 219
 - , use of, 225
 - , value of, 220
- Diamonds, 196
- Distillation, small-scale, 160-161
- Drawings: see 'Diagrams'
- Drying of gases, 65
- Efficiency of the chemist, 112
- Efflorescent substances, 91
- Electricity supply, 270
- Electrolysis experiments, 103, 169-170
- Electromotive force series, 173, 259
- Environment & the Science course, 251-256
- Equations, 182-192
 - , introduction of, 176
- Equilibrium, chemical, 190
- Equipment: see 'Apparatus'
- Errors, constant, 147
 - in quantitative work, 138, 147-152
 - , magnitude of, 146
 - , pupils', 146, 182-185, 212-215, 223-225
 - , variable, 148
- Essay writing, 210
- Ethyl alcohol, 40, 41
- Examinations, 17, and see 'Tests'
- Exhibitions, school, 257-262
- Experimental technique, 236-250
- Experiments, cost of, 109-111
 - , counterpoised, 140
 - , dangerous, 108, 116-119
 - , demonstration, 127-137
 - , electrolytic, 103, 169, 170
 - , individual, 127-137
 - , small-scale, 157-175
 - , solubility, 62, 140, 166, 240
- Explosive reactions, 116
- Facts, presentation of, 31, 81, 200
- Films as visual aids, 233-234
- Fire, precautions against, 113-114
- First-aid, 111, 114, 116, 289
- Formulae, 176, 178-190
 - of common substances, 181, 292
- Fume-cupboards, 267
- Gas, laboratory supply of, 270
- Gases, collection of, 163, 205
 - , composition of, 145
 - , dangerous, 108, 115
 - , drying of, 65
 - in small-scale work, 103, 161-163, 166, 205, 243
 - , preparation of, 65, 105-106, 164, 243, 246
- Generalizing, 38, 64, 241
- General Science, 24-25, 251-256
- Gravimetric analysis, 145
- Hempel's burette, 93
- Heuristic method, 120, 122-127, 203, 242
- History of chemistry, 1-5, 55, 275
- Homework, 68, 69, 243
- Hygroscopic substances, 90
- Hypothesis, definition of, 13
- Improvisation of apparatus, 93, 98-103, 158-175
- Individual methods, 120-127, 132-133
 - , research on, 134-136
- Industrial processes, 8, 31, 222
- Inflammable substances, 117
- Inorganic chemistry: see 'Syllabus'
- Instructions, laboratory, 245

INDEX

Kipp's apparatus, 243

Labels, 89, 283

Laboratory, apparatus for, 86-87, 236-238, 283-288
— assistants, 95-96
— chemicals, 85-92, 103-107, 108, 116-119
— design, 263-271
— instructions, 244
— organization of, 85-119
— records, 87
— rules, 111-113
Language, influence of, 198-207

Law of constant composition, 5
— of conservation of mass, 4, 28, 138, 196, 248-250
— of mass action, 171
— of multiple proportions, 5, 138

Laws, the gas, 67
—, scientific, 13, 178, 193, 194

Lead-chamber process, 229

Lecture-room, 271

Lessons, first in course, 59-62
—, methods in, 62-65
—, notes for, 57
—, preparation of, 32
—, procedure during, 74-76
—, subject-matter for, 51

Library, chemical, 66, 88, 192, 215, 275

Liebig condenser, 101

Lockers, laboratory, 59, 97

Mains services, laboratory, 270

'Makers of chemistry', 2, 3

Marking of note-books, 212

Mathematics, 66

Metallic sulphides, 245

Metallic trees, 173, 259

Metals, 39, 48, 116, 174

Methods in teaching, 33, 56-84
— chemical theory, 176-197
—, Dalton plan, 58
— experimental technique, 236-250
—, heuristic, 122-127
—, laboratory, 120-137
— of girls, 131
—, project, 251-262
— quantitative work, 138-156

Methods in teaching small-scale experiments, 157-175

Micro-chemistry: see 'Small-scale chemistry'

Micro-projector, 235

Minerals, 261

Models, 177, 229-232

Molecules, 177

Museums, 262

Nitrogen cycle, 71

Nitrogen fixation, 70

Note-books, pupils', 209-217
—, —, diagrams in, 218-223
—, —, errors in, 182-184, 213-215
—, —, marking of, 210, 212-217

Notes, taking of, 199
—, —, training in, 208-217

Notice-boards, 225

Organic chemistry: see 'Syllabus'

Osmosis, 174

Oxidation, 245, 247

Oxygen, 244, 246

Ozone, 167

Periodic table, 36

Periodicals, science, 66, 278

Phlogiston theory, 4

Phosphorus, storage of, 89

Physical changes, 207

Physical chemistry: see 'Syllabus'

Potassium, storage of, 89

Practical work, 13, 17, 133, 238
—, organization of, 52-53

Problems, 82, 123, 168-169, 187
—, arithmetical, 153-156, 186
—, practical, 239-250

Projects, 255-259

Pupils, errors of, 146, 182-185, 212-215, 223-225
—, interests of, 73-74

Qualitative analysis, 38, 50
—, small-scale, 170

Quantitative analysis, 4, 107, 122, 138-156
—, gravimetric, 145
—, volumetric, 143-146

Quantities of substances in experiments, 103-107
 Questions: see 'Tests'
 Radicals, 179-180
 —, valency of, 179
 Reagents, storage of, 89, 91
 —, 2N solutions of, 91
 Reference books, 88, 273
 Research, 195-197
 — on teaching methods, 134-136
 — on vocabulary, 202
 Revision, 77, 165, 182
 Rules for the laboratory, 111-113
 Salts, preparation of, 107
 Scientific definitions and words; see 'Language'
 Scientific doubt, 193
 Scientific method, 3, 11, 113
 Screens, film-projection, 233
 Sectional drawings, 220-223
 Side reactions, 69
 Small-scale chemistry, 139, 157-175
 —, advantages of, 157
 Sodium, 64, 230-232, 242
 —, storage of, 89
 Solubility, 62, 82, 99, 140, 240
 Solutions of reagents, 91
 Spelling, 203, 212
 Starch, 172
 Steam distillation, 160
 Stock-book, 85, 87
 Stools, laboratory, 269
 Storage of apparatus, 92-98
 — of chemicals, 88
 — precautions, 89
 Sugars, 172
 Sulphides, 245
 Sulphur, 167, 229
 Sulphur & its compounds, 228
 Sulphuric acid, 81, 229
 Syllabus, advanced, 32-53
 —, elementary, 21-32
 —, general chemistry, 48-50
 —, General Science, 24-32
 —, inorganic, 39, 48-50
 —, modifications to, 68-70
 —, non-specialist, 53-55
 —, organic, 40-46, 51
 —, physical, 48-50
 Symbols, 176, 178, 210, 216
 Teacher, inexperienced, 57
 —, outlook of, 72
 —, qualifications of, 15
 Terminology, 205, 206
 Tests, oral and written, 76-84
 —, classification of, 83-84
 —, for beginners, 200-201
 —, revision, 76-78, 165
 —, varied types, 78-82
 Text-book, 17, 67, 275
 —, diagrams in, 219
 —, use of, 33, 39, 58
 Titrations, 143, 152
 Transfer of training, 13, 19
 Unit apparatus, 162
 Valency, 177-182
 Visual aids, 218, 232-235
 Volumetric analysis, 143
 Water, hardness of, 140-141
 —, project on, 258
 —, laboratory supply of, 270
 Words, scientific, 199, 202, 210
 Written work, 208-212